/3

A REVIEW OF APPROPRIATE ENERGY TECHNOLOGIES FOR HOUSEHOLD USE IN UNDERDEVELOPED AREAS IN SOUTH AFRICA

Stephen Mark Law, B.Sc.Eng. (Chem) *UCT*

Submitted to the University of Cape Town
November 1990

DECLARATION

I declare that this dissertation is my own original work. It is being submitted in partial fulfilment of the requirements for the degree of Master of Science in Engineering at the University of Cape Town. It has not been submitted before for any degree or examination at any university

Signed by candidate 4 November 1990

S M Law

ACKNOWLEDGEMENTS

I would like to thank Anton Eberhard for his help, guidance and moral support throughout the writing of this thesis.

I would also like to thank my friends at the Energy Research Institute for their help in ways too numerous to mention.

To my friends, who didn't always know what I was doing but supported me anyway, you will be glad to know that it's over!

Finally, I am most grateful to Andy, who had faith in me from the beginning.

CONTENTS

LIST OF ILLUSTRATIONS

ACKNOWLEDGEMENTS

The source of illustrations, where omitted in the text, are acknowledged below. Numerals in brackets refer to the page number where the illustration occurs, followed by the source reference.

*(83)*Energy Research Institute,1990; *(84)*Cawood,1988; *(92)(93)*Basson,1988; *(146)*Emrich,1985; *(143)(145)(144)(158)(159)(174)*Kristoferson & Bokalders,1986; *(156)*Evans & Boutette,1981; *(157)*Peat Warwick Mitchell,1987; *(160)*ATS Newsletter,1989; *(172)*Van Buren,1979; *(173)*Sasse,1984; *(181)(182)(183)(184)*Pinon,1983; *(193)* Ibraham et.al.(1986)

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1. Background

All productive human activities require energy, and it's use is an important factor in the economic growth and development of a society. The need for improved levels of material well-being has stimulated the discovery of new and more efficient ways of harnessing energy, enabling societies to exercise greater control over their environment and productive activities. The progression from muscle-power and firewood to wind and water power, through to the development of energy intensive technologies using fossil fuels and nuclear power has allowed the expansion of economic and productive activity of societies, which has in turn reflected and influenced the nature of their political and social structures. However, the comparative pace of economic development between societies and between different sections of a society has seldom been equitable. Indeed, it can be argued that the development of some societies has taken place at the expense of the underdevelopment of others (see Rodney,1974; Cardoso,1973 and various works of A.G.Frank).

The inequitable pace of development in different sections of society is notably visible in South Africa where the gulf between the "First World" (mostly wealthy, urban and developed) and the "Third World" (mostly poor, rural and underdeveloped) is particularly wide, despite the two "worlds" being inextricably linked. This polarisation is most evident in access to resources and services such as land, health care and education, and levels of poverty. It is also evident in patterns of energy use. To many South African households, energy in the home is taken for granted. Electricity runs the fridge and stove, heats the bath water and allows rooms to be lit at the flick of a switch. Electricity is provided cheaply and is available for a multitude of domestic uses, from the essentials such as cooking and heating to more luxury applications such as personal computers, radios and TV. However, an estimated two-thirds of our population (more than 20 million people) do not have access to electricity, and have no choice but to use fuels such as coal, paraffin, candles and wood which are in many ways inappropriate to their needs. In these households, meeting energy requirements can be a major problem.

In rural "homeland" areas, the struggle to meet daily household energy requirements has been illustrated in a number of recent energy surveys. The major source of fuel in rural "homelands" is wood, traditionally a "free" resource collected from surrounding woodland, but its increasing shortage is causing intensified hardship. In a survey by Gandar (1983), one extreme case showed a group of women sometimes walking up to 19 km on a round trip to collect 40kg headloads of wood, an arduous journey which was repeated two to three times per week. The shortage of "free" or easily collected wood is also forcing people to use marginal fuels such as grass and dung, or to spend a greater proportion of their meagre cash resources buying wood or fossil fuels from traders. The dependence on wood and its increasing shortage results in hardship, time and effort wasted that could be put to more productive activities, and a financial burden on impoverished households. In the longer term, the multiple and complex ecological and social consequences of deforestation are likely to be severe. These include a wide range of inter-linked effects such as erosion, loss of soil fertility, reduced agricultural capacity, stock loss and malnutrition.

In the squatter-camps and shanty towns of the "informal" areas, sandwiched as they are between rural areas and urban centres but without the benefits of either, households are not able to collect "free" wood; nor are they allowed access to electricity and are forced to use fuels such as coal, paraffin, candles and car batteries. These fuels are in many ways inappropriate to the high-density living conditions in urban areas. The safety hazard they pose is evident in the almost daily newspaper reports documenting yet another "squatter shack" that has been razed, sometimes with fatal results, because a burning candle was knocked over, or a paraffin stove left unattended. Fossil fuels burned in badly ventilated kitchens contribute to respiratory and eye disease, while similar health problems are caused by the severe particulate air pollution from coal stoves which hangs over many of the overcrowded townships.

Without access to "free" fuel as in the rural areas, poorer households in urban underdeveloped areas spend a disproportionate amount of their household budget on energy, from 10 to 25 percent compared to around 3% for households in middle-class electrified areas (Eberhard,1984:9). These problems are not confined to the so-called informal settlements. Many of the established black townships, some dating back to the 1950s are still without electricity or are only partially electrified, despite their bordering on fully electrified industrial or residential areas. Residents in these "formal" townships are similarly forced to use inappropriate and expensive fuels.

The consequences of the problematic energy consumption patterns in underdeveloped areas have essentially two components. Firstly there is the immediate element of human suffering. Meeting energy needs in these households involves disproportionately large amounts of time and effort or precious earnings, which could be better spent on more productive activities. The cycle of poverty and deprivation cannot be broken. Secondly but equally important are the longer term implications of the continuation of these energy use patterns, most importantly, the potentially disastrous environmental effects of deforestation in the "homelands".

Some of the problems associated with present energy consumption patterns in underdeveloped areas can be addressed through a technological response, and a large portion of this thesis is devoted to discussing appropriate technological responses. However, the "energy problems" cannot be seen in isolation from the conditions that give rise to them. Given the link between these problems and the more fundamental social inequalities in our society, any solution must involve more than merely a technical fix that removes the symptoms. Technical solutions need to be aware of the unique political dimension of underdevelopment in South Africa and should involve a direct response to real and expressed needs, not only easing immediate hardship, but also addressing the processes that maintain these conditions.

1.2. The Objectives and Relevance of this Thesis

The development of technologies and structures providing energy for household use in South Africa have for many years been dominated by the needs of "white" households. While these needs have been comprehensively met through cheap and efficient energy supplies, the needs of those in the "homelands" and townships have effectively been ignored. Thus, for roughly two-thirds of the population in South Africa, the struggle to meet basic energy needs for cooking, water heating, space heating and lighting is time consuming and expensive. The planning of a national energy strategy for the future can no longer overlook the energy needs of underdeveloped areas. While the immense task of building institutions and techniques for providing all with adequate and affordable energy supplies will require substantial technical intervention and a large amount of capital, ignoring these problems will incur even greater political, social and environmental costs.

Interest in the field of energy for underdeveloped areas has been increasing in recent years, and has led to research on various appropriate energy technologies and the highlighting of energy problems in various locations. However, there has been no overview of experience to date, nor any comparative assessment of these technologies and their potential role in an energy supply strategy. By drawing together the body of research into one publication, this thesis hopes to provide an overview, to allow different energy technologies and supply options to be assessed and compared, and to provide a starting point for debate on suitable energy strategies for underdeveloped areas.

Since the thesis covers such a wide range, the discussion on individual technologies is limited to a rather cursory analysis. Where possible, references are given which would allow the reader to pursue a particular subject in more detail.

1.3. Scope of this Thesis

This thesis is primarily a literature survey and critical review of work done on the field of energy supply in underdeveloped areas in South Africa. The discussion is bounded by the intersection of three main areas:

Firstly, the application of these technologies is confined to basic household energy needs i.e. the energy required by individual households for cooking, water heating, space heating and lighting of their homes. In townships and "informal" settlements, the major portion of energy consumption is used to fulfill these basic household needs. Energy for use in communal activities, industry or commerce is not considered. In rural subsistence communities, it is much more difficult to separate household energy consumption used in meeting domestic needs and that which contributes to agricultural productivity. However, those obviously agricultural or communal energy consuming activities such as water lifting, ploughing, grinding and the like will not be considered.

Secondly, discussion is confined to households in underdeveloped areas. Essentially, these areas should be defined by socio-economic considerations, although in South Africa political ideologies of the past have defined its geographic, class and racial boundaries. In this thesis, rural underdeveloped areas include households in the "homelands" and "national states", and black labourer households living on white-owned farms. Urban underdeveloped areas include the shanty-towns, squatter-camps and informal settlements associated with metropolitan centres, as well as low-income households in formal black townships[1]. While there are a number of similarities in the

1 The terms "black urban areas" or "homelands" are used as defined by the Group Areas Act for the former, and the Land Acts and subsequent legislation for the latter. At the time of writing, these two acts are still in force.

nature and causes of energy problems in rural and urban underdeveloped areas, there are also distinct differences, such as poverty levels, settlement patterns, access to resources and expectations which make it necessary, when offering energy technologies and energy supply strategies, to draw a general distinction between rural and urban situations.

Thirdly, the energy supply technologies reviewed here are those that have the potential to provide adequate and affordable energy supplies for meeting basic energy needs. However, it is not enough to consider merely the "nuts and bolts" of good design, good quality, low-cost and easy maintenance. To be appropriate, any technological intervention has to take place within a development context, and the outlining of a suitable context will also be discussed.

1.4. Thesis Structure

The main focus of this thesis is the review and assessment of a range of appropriate energy supply technologies for household use in underdeveloped areas. However as a basis to understanding the problems these technologies hope to ameliorate, Chapter 2 will quantify current energy consumption patterns, and discuss the nature of the "energy problems" facing households in underdeveloped rural and urban households respectively. It will also compare energy consumption in underdeveloped areas with national consumption figures and discuss the overall distribution of energy resources in South Africa, and South African energy policy.

Chapter 3 will review a range of appropriate energy technologies for domestic use in urban underdeveloped areas. These include grid electricity, solid fuel from waste,solar water heating, and passive solar design of houses.

Chapter 4 will review a range of appropriate energy technologies for domestic use in rural underdeveloped areas. These include afforestation, charcoal making, fuel efficient stoves, biogas, solar cookers, hotboxes, solar water heating, passive solar design of houses, photovoltaic electricity, and rural electrification.

For each technology reviewed in chapters 3 and 4, the discussion includes how the technologies operate, how much they cost, the state of progress in the respective fields, case studies where applicable, and a look at their potential in South Africa.

The energy problems discussed in Chapter 2 are symptoms of underdevelopment. The eradication of these problems thus requires a development strategy within which the energy supply technologies reviewed in chapters 3 and 4 can be located. Chapter 5 will discuss Basic Needs Fulfillment as an effective development strategy and will outline some of the problems around the dissemination of energy supply technologies.

CHAPTER 2

ENERGY CONSUMPTION PATTERNS IN UNDERDEVELOPED AREAS AND THE DISTRIBUTION OF ENERGY RESOURCES IN SOUTH AFRICA

2.1. Introduction

Prior to reviewing individual energy technologies, this chapter will attempt to illustrate the most pressing energy problems facing households in both rural and peri-urban underdeveloped areas, through an examination of current energy consumption patterns in these areas and the inequalities in the national distribution of energy resources.

There are many pitfalls on the way to defining "energy problems" in underdeveloped areas. In many cases they are defined or characterised empirically as a set of problematic symptoms, such as distribution of and access to energy resources, cost of fuels and the social problems inherent in the end-use of a particular energy source. While such data may provide a measure of prevailing conditions, the real dimensions of the problem cannot be so easily or unambiguously specified. For example, what can be statistically measured as a fuelwood shortage in rural areas may have many causes. Deforestation may be due to a demand for fuelwood, but also to increasing pressure for more arable land, agricultural practice or changing weather patterns.

Problems with adequate and affordable energy supply in underdeveloped areas do not exist in isolation from other aspects of life and energy cannot be regarded as an entity separate from other household inputs. Energy is an integral part of living and the patterns of it's use are influenced by a myriad of forces. It is but one small aspect of a wide and dynamic process affecting the social, economic and political life of households. Surveys illustrating the "energy problems" and outlining "energy needs" are often limited by this inherent complexity, reflecting only the superficial symptoms of a current condition. How well they do or do not approach the wider dimensions of the problem, is largely dependent on the type of survey, its scope, and the subjectivity of the researcher. There are shortcomings common to many surveys and statistical pictures describing the "energy problem" in underdeveloped areas:

- Most cross-sectional surveys give a "snap-shot" picture and are unable to indicate the dynamics of energy use patterns. Needs and demands recorded in energy surveys are usually a direct function of (among others) resource availability, fuel prices, household incomes, habits and traditions. These and other influences which may be constantly changing are often not reflected. A further consequence of the multi-variate forces affecting energy use is that energy surveys in one area, or on one section of a community can seldom be extrapolated to provide an accurate general picture or model.
- Communities themselves seldom see energy problems in isolation, but rather as a part of other problems. A shortage of fuelwood, for example, may be seen as a subset of a more general timber shortage including wood use for building materials. On the other hand, the dependence on fuelwood may be seen as due to insufficient income to purchase preferred commercial fuels such as paraffin, gas or electricity.
- Communities usually also have a priority to their needs which may not be uncovered by a purely energy-based survey. The success of a technological response to energy needs may depend on prior satisfaction of the more important non-energy needs.
- Households are generally unable to articulate a need for something they know little about. Households that have not already been exposed to electricity for example, will not be able to clearly express it as a need.

Considering the limitations of energy surveys, examining energy use patterns and defining the dimensions of "energy problems" in underdeveloped areas, as this chapter does, holds the danger of viewing these problems in isolation from their essential determinants. The danger lies in offering solutions that relieve the symptoms but do not address the real causes. As far as possible, this thesis has tried to be aware of the complexities of energy use and the limitations of defining "energy problems".

2.2. Energy Consumption Patterns in Underdeveloped Areas

The existing knowledge of energy consumption patterns in the underdeveloped areas in South Africa stems largely from surveys conducted over the past decade. In rural areas, surveys have documented energy use patterns and highlighted the problematic dependence of households on the decreasing availability of fuelwood. In urban areas, energy surveys have highlighted the disparity in household energy consumption between black and white areas, and some of the problems associated with the limited energy supply options open to non-electrified households.

Most of these surveys have also highlighted the variations in energy consumption between different households in the same area, on different days for the same household, and generally between the seasons. When comparing different energy surveys, one is also struck by the wide variation in data from place to place. Eberhard (1986a:7) has attributed climate in the case of rural areas, and type of settlement pattern in the case of urban areas, as being two major causes of these variations, and in an attempt to provide a national picture of household energy consumption patterns in underdeveloped areas, surveyed six rural villages in different bio-climatic zones throughout the country, and five urban settlements of different "degrees of urbanisation". Data from this survey indicating the relative popularity of different fuel types used in households in underdeveloped areas is given below.

Table 2.1. Percentage of Households in Underdeveloped Areas in South Africa Using Different Fuels.

FUEL TYPE	% HOUSEHOLDS USING FUEL			
	Rural Homeland	Rural Farms	Peri-Urban	Town-ships*
Electricity	<1	14	3	29
Wood	99	97	68	38
Wastes	80	30	22	2
Paraffin	96	19	84	71
Candles	73	86	79	77
Coal	12	5	53	47
Gas	5	9	7	14
Batteries	55	?	60	?

Source: Eberhard (1986a); and *Moller (1985) in Eberhard (1989)

Some important features can be drawn out of the table above, namely:
- the low frequency of grid electricity users, particularly in rural and peri-urban areas;
- the drop in frequency of wood users with increased degree of urbanisation; and throughout,
- the prolific use of candles (and batteries) for lighting; and
- the high degree of multiple fuel use.

Further insight into fuel use patterns can be gained by looking at the consumption figures for different fuels. As mentioned above, a characteristic of energy surveys is the wide variation in consumption data from household to household, from place-to-place and the "averages" reported by different surveys. The table below illustrates this for rural fuelwood consumption.

Table 2.2. Comparative Fuelwood Consumption Data in Rural South Africa

REGION	CONSUMPTION (kg/capita/annum)	SOURCE	
Transkei, Jozannas Nek	270	Best	(1979)
Bophuthatswana	404	Eberhard etal	(1987)
Transkei, Nkanga	498	Eberhard	(1986a)
Gazankulu, Cottondale	572	Eberhard	(1986a)
KwaZulu (highveld)	620	Gandar	(1988)
KwaZulu (valley lowveld)	740	Gandar	(1988)
Gazankulu	760	Liengme	(1983)
KwaZulu, Mashunka	1120	Best	(1979)
MEAN	623		
STANDARD DEVIATION	259		

Source: Aron et.al. (1989)

A similar trend exists with other fuels. The consumption of paraffin in one survey (Eberhard,1986a) ranged from 10 to 43 l/cap/annum in rural areas and from 17 to 96 l/cap/annum in peri-urban settlements. There is also a wide variation in the extent of coal use which, for urban households, follows a distinct pattern with high consumption in Transvaal townships and relatively low consumption in the Western Cape. Some of the factors which influence the choice and consumption of fuels will be discussed later.

The point to be made here is that the wide variation in data makes it almost impossible to present an accurate "national average consumption" for a specific fuel. There is also some doubt as to the usefulness of presenting such an average as an indication of fuel use patterns. As will be shown in later sections, a major constraint to suitable and adequate energy supplies in underdeveloped areas is the unequal distribution of resources. These inequalities are evident not only between developed and underdeveloped areas, but also between various underdeveloped areas themselves, and in smoothing out these inequalities to produce an average, one loses this important dimension of the overall energy problem. Nevertheless, it is important to provide some idea of the quantitative dimensions of fuel use in underdeveloped areas. The table below indicates a mean annual per capita consumption figure for households in rural and peri-urban areas, and is drawn from possibly the most comprehensive energy survey to date.

Table 2.3. Mean Annual Per Capita Domestic Fuel Consumption in Underdeveloped Areas in South Africa.

FUEL TYPE	Rural Homeland	Peri-Urban
Fuelwood (kg/cap)	604	334
Dung (kg/cap)	118	—
Paraffin (l/cap)	23	46
Candles (no./cap)	27	51
Coal (kg/cap)	20	156
Gas (kg/cap)	0.66	1.90

Source: Eberhard (1986a:106)

From this information, the significant position of fuelwood in both rural and peri-urban areas is clear, although in the latter it is increasingly replaced by fossil fuels. While energy consumption measured in fuel units gives an idea of the physical demand, it is more informative to look at consumption in energy units (nett energy) of each fuel, and by the energy they provide after conversion (useful energy).

The nett energy consumption is a function of the inherent energy content of each fuel. The energy content or calorific value of fuels can be accurately measured in a laboratory and the following values have been used (Eberhard,1989:4):

Coal - 27 MJ/kg
Paraffin - 37 MJ/l
Gas - 49 MJ/kg
Wood - 17 MJ/kg (air dried, 15% moisture)
Dung - 12 MJ/kg (air dried)

Values used by the United Nations vary slightly with gas 45,5 MJ/kg and paraffin 43,2 MJ/kg and on this basis would slightly increase the energy contribution of paraffin and reduce that of gas (Viljoen,1989:83).

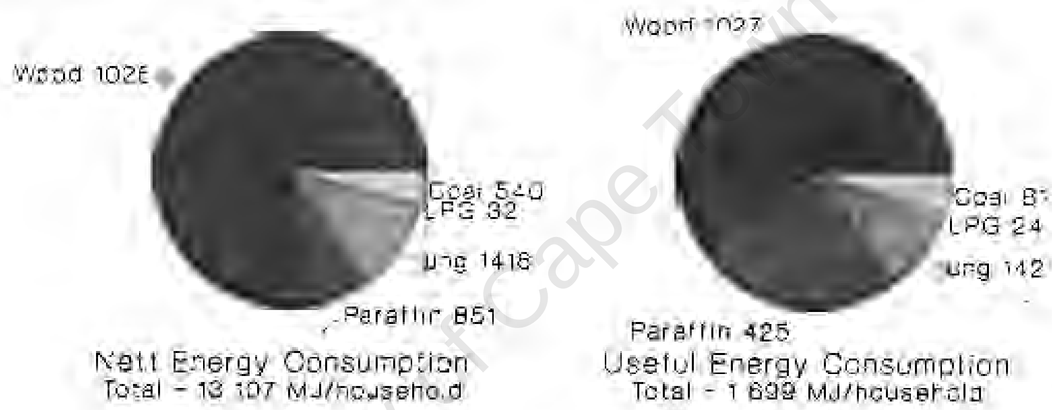
Useful energy consumption is a measure of the useful energy supplied by the fuel and takes into account the efficiencies of the various energy appliances used. Only stoves are considered since it is assumed that cooking and water heating account for the major portion of fuel consumed. Realistic efficiency values for various appliances are more difficult to gauge since efficiency tests in the laboratory cannot accurately model the real situation, and ignore important variables such as wind strength, size, type and condition of cooking pot and condition of the appliance. The following values have been used (Eberhard,1989:4):

Coal Stove - 15%
Paraffin Stove - 50%
Gas Stove - 75%
Shielded Wood Fire - 10%
Electric Stove - 80%

Again slightly different figures are obtained from other sources (Viljoen,1989:83) and appliance efficiency should strictly be presented as a range of values. However, for the purpose of illustrating the effect of appliance use on fuel consumption, the figures above are acceptable.

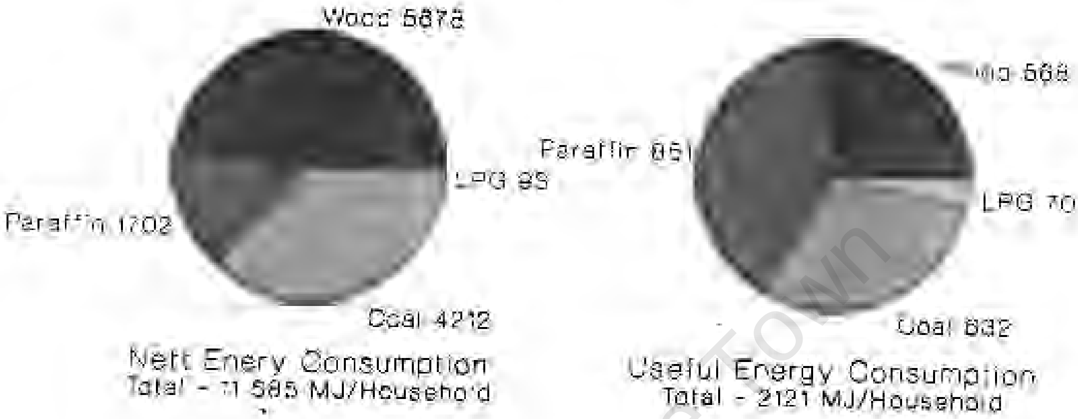
The charts below show the nett and useful energy contribution of each fuel to the total consumption for rural and peri-urban households. Consumption of candles and power from car batteries are not indicated in the charts, because, while they are widely used, their actual contribution to overall energy consumption is very small.

Figure 2.1. Mean Annual Domestic Consumption per Rural Household per Fuel



<u>Source:</u> Eberhard (1989)

Figure 2.2. Mean Annual Domestic Consumption per Peri-Urban Household per Fuel.



Source: Eberhard (1989)

These charts show that in terms of energy consumed and energy utilised, wood is still by far the most important fuel for rural households. In peri-urban areas however, while large quantities of wood are burned, it is fossil fuels (notably paraffin which has a high conversion efficiency) which provide the major portion of the energy utilised. The dominant position of paraffin would possibly be replaced by coal in areas where it is available and cheap. What is also clearly evident from the diagrams above is that while the mean per capita nett energy consumption is slightly lower in peri-urban areas, the useful energy consumption is higher, indicating the use of more efficient fuels and energy appliances by households in peri-urban areas.

The problems of adequate and affordable energy supply in underdeveloped areas, in as much as they concern specific fuel use, are obviously closely matched with the kind of consumption patterns shown above, however a clearer understanding of the energy problems requires looking at the forces which determine these patterns.

2.3. Some Key Determinants of Energy Consumption and Fuel Use in Underdeveloped Areas

The kind of household energy consumption patterns typical of rural and peri-urban underdeveloped areas result from a number of economic, social and political forces. These forces are complex and dynamic, and are difficult to isolate or define clearly but nevertheless, some key determinants can be recognised from existing data (Eberhard,1989). They are discussed below.

2.3.1. Level of Urbanisation

Perhaps the most obvious pattern emerging from the information above shows the relation between the level of urbanisation on the one hand, and energy consumption and fuel type used on the other. There are a number of factors which characterize the difference between households in rural areas and those in urban settlements. Those which reinforce the correlation between urbanisation level and fuel use patterns include general standard of living and aspirations, the existence of fuel distribution networks (usually more advanced in urban areas), the range of optional fuels and their respective prices, and the increasing commoditisation of fuel as the opportunity for collecting free wood disappears with increasing level of urbanisation.

As can be expected, the dominant position of wood in rural areas is replaced by a mix of fossil fuels in urban areas, with paraffin and coal predominant. Paraffin is widely used in both rural and urban areas although consumption is higher in the latter. While the mean per capita nett energy consumption is less in peri-urban areas, the equivalent useful energy consumption is greater, indicating a higher energy demand and also a switch to more efficient fuels and appliances.

2.3.2. Site Specific Factors

Apart from the urban/rural difference, most energy surveys have shown that the form and quantity of energy used is different for different settlements in both rural and urban areas. Variations can be fairly marked between individual rural villages and can be largely attributed to the local availability of "free" wood. The proximity of rural villages to urban centres will also affect availability and price (and thus consumption) of commercial fuels and energy appliances.

Households in urban and rural settlements in the Transvaal and Free State, particularly those near to major towns or railheads show a much higher consumption and usage of coal than the coastal areas of the Cape Province, a product no doubt of relative availability and price (Viljoen,1989). Regarding the use of electricity, this is obviously confined to a small group of households in electrified townships, and of course totally excludes the "informal" urban areas.

Climatic conditions also influence energy consumption with colder inland regions generally showing higher figures, particularly over the winter months.

2.3.3. Other Determinants

The choice of fuel type and consumption rate is influenced by a complex set of factors and only two obvious ones have been discussed above. Another key determinant is the make-up and size of the household, which influences both quantities of fuel used per household and per person, and the type of fuel used.

A recent survey by Viljoen (1989) looking at fuel consumption patterns in formal and informal black urban areas has highlighted the difficulty of explaining fuel use patterns in terms of just a few single unrelated variables. This study of energy use in the context of rapid urbanisation indicated that neither fuel type nor fuel consumption correlated well with household income, although no doubt the relative importance of fuel in the family budget decreases as incomes increase. However, a strong relationship was found between energy use patterns and a household's degree of "modernisation". This variable could be indexed as a combination of factors, inter alia, the length of time the household has been urbanised, degree of residential mobility, type of dwelling, car ownership and TV ownership. This research has highlighted the importance of understanding the dynamics of fuel use patterns in the context of rapid urbanisation, possibly one of the most significant social processes currently taking place in South Africa, and a phenomenon that will shape the lives of millions of South Africans in decades to come.

The static picture presented by energy use patterns and the problems associated with them (discussed below), can be given an added dimension by looking at the projected future population growths, and shifts in settlement patterns for South Africa shown in the table below.

Table 2.4. Current and Projected Population Distribution of Black people in South Africa.

SECTOR	*1980* POPULATION (Million)		*2000* POPULATION (Million)	
Metropolitan	3.96		8.90	
Urban	3.20		6.89	
Fringe	1.45		3.92	
Rural	12.12		15.06	
TOTAL	20.74	100.0%	34.77	100.0%
% Urban		34.5%		45.4%

Source: Simkins (1985)

According to these projections, South Africa will experience a significant population increase, particularly in urban and "fringe" areas. The urgent need for solutions to the energy problems currently experienced in underdeveloped areas will intensify, particularly in these areas, where response to welfare needs of households has consistently lagged behind demand.

2.4. The Problems Around Current Energy Use Patterns in Underdeveloped Areas.

2.4.1. The Urban Energy Problem

A universal feature in urban energy surveys is the high proportion of the family budget of low-income, non-electrified urban households which is devoted to basic energy expenditure. These households spend between 10 and 20 percent of their incomes on basic energy requirements alone, compared to 5-7 percent in similar, but electrified areas, and 3 percent in white middle-class suburbs (Eberhard,1986a). Some surveys (Dept of Health,1977; Rivett-Carnac,1979; Eberhard,1984) have shown that some un-electrified households may even spend more on fuel than similar electrified ones.

This situation arises from the fact that the fuels typically used by low-income households, although inconvenient, messy, dangerous and considered by many as inferior to electricity, are in terms of the useful energy obtained, not significantly cheaper than electricity. The table below lists the ranges of fuel costs based on useful energy.

Table 2.5. Comparative Retail Fuel Prices and Energy Cost (Approximate - 1988/89)

FUEL TYPE	RETAIL PRICE RANGE		USEFUL ENERGY COST RANGE (c/MJ)
Electricity	9 – 11	(c/kWh)	3.1 – 3.8
Paraffin	56 – 63	(c/l)	3.1 – 3.4
Gas	120 – 160	(c/kg)	3.3 – 4.4
Coal (Cape)	25 – 45	(c/kg)	6.2 – 11.1
Coal (Tvl)	12 – 16	(c/kg)	3.0 – 3.9
Wood	10 – 20	(c/kg)	5.9 – 11.8

Source: Viljoen (1989) & Misc.

Fuel prices tend to vary widely and are thus presented above as a range of values. In the case of urban electricity, the price is usually set by the relevant local authority or municipality, who buy bulk supply from Eskom or operate their own power stations. The actual cost to the consumer generally includes other charges for services and capital redemption, depending on what costs the authorities have to recover. Electricity can be particularly costly in newly electrified townships where residents have to pay for housewiring, connection fees, and a high monthly capital redemption fee. The retail prices of coal and paraffin are not controlled and are strongly dependent on the distribution and retail system. Transvaal coal for example, is one of the cheapest wholesale fuels, but once bagged, transported and distributed through vendors, its price may double. The price of paraffin sold from township suppliers is usually dependent on the quantity purchased, and may also vary in price from place to place. In both cases, poorest households tend to pay the higher prices because their purchases are made in small quantities and they are seldom in a position to "shop around" for the best price.

For low-power applications such as lighting, energy costs can also be expensive. Energy from candles, a typical source of light, costs around 295 c/MJ (Eberhard,1984:6), compared to grid electricity at 10 c/MJ at the very most. Low-power electrical appliances such as TV sets and radios are commonly run off dry-cell batteries, car batteries or in some cases small petrol generators. Car batteries are an extremely expensive source of energy and are particularly unsuitable for deep-discharge cycles such as in home appliances. The lifespan of a standard lead/acid motor car battery which is drained until flat is around 50 charge/discharge cycles. This will increase to about 1000 cycles if it is only drained to 50% of capacity. Assuming a household uses a small 12 V, 60 Ah car battery costing about R80 to run a 30 W television set for 5 hours per day; and assuming they run it flat and pay R3 each time it is recharged, the per unit cost of energy is about 600 c/kWh, almost 60 times more expensive than grid electricity. Batteries specifically designed for deep discharge cycles are more expensive (about R180), but can reduce the cost of energy by roughly one half.

There are other economic considerations besides energy cost, which would influence energy consumption patterns, notably, the cost of appliances. Wood for cooking and heating requires nothing more than a space on the ground, and coal can be burned in a homemade brazier. Candles too, need no special appliance. Paraffin and gas require stove or lighting appliances which can cost anything between R15 and R60, and a coal/wood stove can cost from R200 upwards. Electrical appliances are the most expensive, and these, together with connection fees and housewiring can put a cheap and desirable energy form completely out of reach of a significant proportion of new consumers.

While it has been illustrated that grid electricity, as a fuel, is no more expensive than the commonly used wood, coal candles and paraffin, electricity is also considerably more appropriate to conditions of high-density urban living. The health and safety risks associated with the burning of wood, coal, candles and paraffin fossil fuels stem chiefly from pollution and fire danger. Pollution from coal in Highveld townships is severe, particularly in the cold winter months when temperature inversions prevent the smoke from rising and dispersing. Soweto burns more than half a million tonnes of coal each year, and given the high ash content of South African coal, it is estimated that approximately 10 000 tonnes of ash is released annually into the atmosphere over Soweto (Eberhard,1986b:9), about 5kg for each person. Fumes from burning wood and fossil fuels in crowded, enclosed areas is a major contributor to respiratory disease amongst adults and particularly children. The fire hazard posed by these fuels is also great, and exacerbated by inflammable building materials and almost non-existent emergency services in the "informal" areas.

Paraffin consumption makes up a large part of the total fuel consumption in townships and rural areas, and as such is an important fuel. It is a by-product of the country's petroleum industry, and is therefore available at a substantial de facto subsidy. However, the fact that it is widely used is no indication of its true "popularity", since the households among which it is most widely used are those not in a strong position to use other more convenient, safer, cleaner and more healthy fuels. The health and safety problems associated with burning fuels such as paraffin are exacerbated by severe overcrowding in many black townships and informal urban areas. Wilson & Ramphele (1989:125) quote studies giving estimates of 17 to 20 people per house in Soweto and a mean of 5.6 persons per room in Elsies River, both formal townships. In informal areas, the density tends to be lower but living conditions are poorer. In addition to overcrowded conditions in individual houses, black urban areas in general are densely populated. The same authors (pp126) report 626 to 825 people per hectare in Alexandria, Johannesburg, more than ten times the density of nearby "white" (and electrified) Sandton.

On the surface, the "energy problem" in black urban areas stems mainly from the inappropriateness of fossil fuel use in crowded urban conditions, and from the high cost of these fuels. However, these problems cannot be isolated from general living conditions in these areas. They exist rather as blocks in a matrix of related problems, some the cause of, and some the result of poverty levels and underdevelopment in these unplanned and neglected residential areas.

2.4.2. The Rural Fuelwood Problem

The primary fuel for households in rural "homeland" areas is wood, which is used for cooking, space heating, water heating and even lighting. Wood has been the traditionally used fuel for thousands of years and is also widely used as a building material. With the supply of electricity to rural areas still a long way off, and while the substitution of fossil fuels may reduce dependence on wood, it is likely to remain the single most important basic household fuel in rural areas for some time.

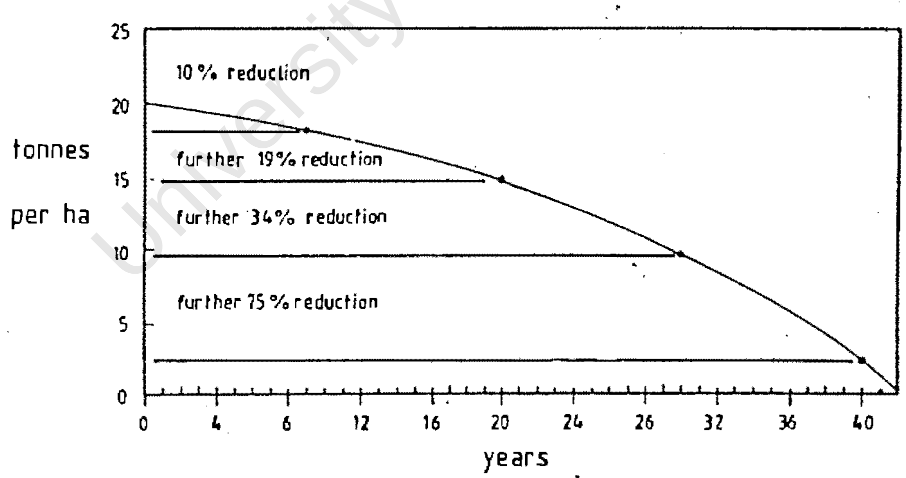
The use of wood as a domestic fuel is problematic firstly because of the inherent dangers to health and safety by using it on a daily basis. Rural energy studies often mention the link between eye and respiratory disease caused by an almost constant exposure to wood smoke, particularly in winter or bad weather conditions when fires are made indoors. Woodfires however, also have advantages. Wood fuel may in fact be the preferred option for poorer rural households in that it is potentially renewable, requires only time and effort to collect and no expensive or complex appliances are needed to extract its energy. Wood also does not need the special safety precautions that go with using and storing paraffin or gas, nor the complex housewiring system required for electricity. Even the smoke from indoor fires is beneficial, protecting thatch roofs, and the grain stored under them, from attack by insect pests (Foley et.al.,1984:21).

The major energy problem facing rural households is not so much the unsuitability of wood as a fuel, but rather its increasing shortage. In some rural areas, wood is in plentiful supply close to villages, but in most, it is difficult to procure or is only available as a cash commodity along with coal, paraffin and gas. In areas of extreme deprivation, people resort to cutting down green wood (Gandar,1984:5) or are sometimes forced to make do with inadequate supplies. The continued use of wood can also lead to deforestation along with some potentially disasterous environmental effects.

Accurately quantifying the extent of deforestation and wood shortage on a national scale is not only an enormous task but also one that would have to be stretched over a time period of five or ten years in order to gather sufficient information. To date, most evidence of the shortage is anecdotal. Interviews with rural households have shown an awareness of the deteriorating fuelwood supplies (Gandar,1983; Eberhard,1986a) although individual views on the seriousness of the situation vary from place to place. Steps are being taken to support this evidence on a more scientific basis, one of these being the use of LANDSAT satellite images. Satellite imagery however, does not seem to have the necessary resolution to discern changes in the woody biomass production of woodland and scrubland savanna from which the major portion of fuelwood is gathered.

Perhaps the most comprehensive attempt at quantifying the fuelwood shortage to date has been the projection by Aron, Eberhard and Gandar (1989) showing that overall demand for fuelwood in the South African "homelands" exceeded the supply from natural woodland soon after 1980, and predicting that natural woodland would be almost totally denuded by the year 2020, should demand continue at current levels. The model firstly combines the data from a number of energy surveys with current and projected population figures to give an approximate fuelwood demand estimate for the South African "homelands" to the year 2000. Proposing that the major supply of wood for fuel arises from naturally occurring woodland and shrubland covering most of the uncultivated homeland area, the model secondly estimates the biomass growth rates in the various vegetation regimes occurring in the "homelands", and with certain correction factors added, provides a supply/demand for each homeland region. Balancing demand against sustainable supply, the model provides a projection of the deforestation of woodland areas, and shows how woody biomass stock is reduced over time

Fig 2.3. Projected Reduction of Woody Biomass Stock



Source: Aron et.al.(1989)

The model described above incorporates a number of simplifying assumptions, the most significant being the assumption that demand per capita for woodfuel is unaffected by decreasing supply. As Foley (1988:4) has argued, it is incorrect to equate the present measured consumption with a fixed unchanging demand. More realistically, demand and consumption are functions of availability, in other words, consumption declines as wood gets scarcer forcing people to switch to other fuels such as paraffin, dung, grass and twigs (there is evidence of this happening already), and at some point balancing supply and demand. This however does not mean that the energy problems will disappear, since the demand for energy will still increase and the switch to other fuels may introduce a new set of problems. Despite a forced switch away from wood as it grows scarcer, there is a real danger that in some areas, deforestation and the resultant ecological damage to natural woodland ecosystems will be irreversible.

While the accuracy of this type of supply/demand model can be questioned, the seriousness of the problem cannot. The work by Aron et.al. is welcomed in that it supports the largely anecdotal information on deforestation and the shortage of wood and also provides a "scientific" basis for further action. Deforestation and its related problems are undoubtedly of national importance, requiring action on a large scale, and it is precisely comprehensive models such as this that are needed to alert policy makers and officials to the urgency of the situation.

The consequences of wood demand outstripping supply are essentially twofold. The first and most immediate manifestation is the increased social cost to households, notably in the time spent collecting firewood that could be put to more productive use. Best (1979) records times of 12 to 15 hours per week per household for firewood collection, Gandar (1983), a figure of 7 to 9 hours per week and walking distances of up to 8km per round trip. In addition to time spent on collecting wood, the distances involved and the weight of a headload of wood, typically around 35kg, represent an arduous and energy sapping task. As Gandar states, "..if wood gathering is counted as part of food preparation, more effort is consumed by the preparation of food than the growing of it." (Gandar,1984:9).

It is also evident that the shortage of wood in some areas has lead to the commercialisation of this once "free" resource. Moller (1985) reports that 45% of households in KwaZulu and Lebowa purchase wood. Similar figures are given by Eberhard (1986a) who also notes that in many cases, the picture of women collecting headloads is being replaced by one of men with tractors, trailers and pickup trucks. In such cases, the major cost is in the transportation rather than in the collection of the wood. Transport costs are variable with distance and can account for as much as 80% of the delivered price (Eberhard,1986a:37). The arduous task of collecting wood is now being replaced with the problem and cost of securing suitable transport. In most areas with a wood shortage, expenditure on wood constitutes the largest component in the household energy budget, and this is for households who can least afford it.

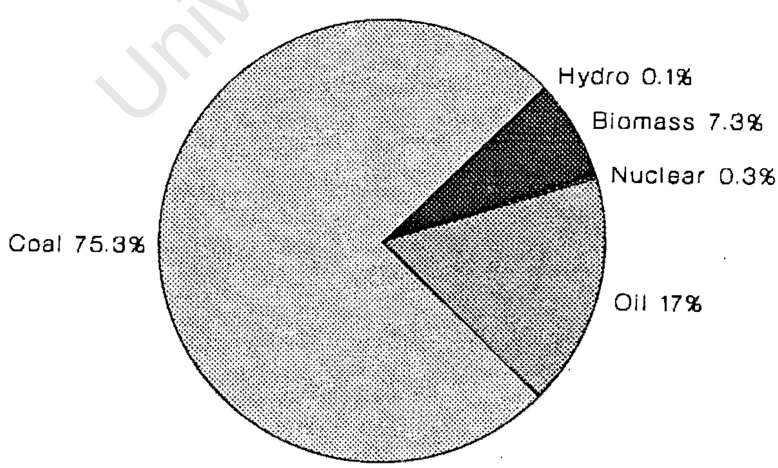
The second serious consequence of the supply/demand deficit is the potential ecological damage due to deforestation, although this is also caused by agricultural clearing, harvesting of building material, and veld-fires. Deforestation does not just mean the loss of trees, but because of the inter-dependence of ecological systems, could lead to loss of land fertility and erosion. It also forces rural people to turn to marginal fuels such as leaves, grass and dung further upsetting the ecological balance, thus accelerating the decline of soil fertility caused by loss of tree cover. Deforestation, from whatever cause can have a long-term and multi-pronged effect. Through upsetting the natural ecological balance, deforestation can set off a series of "chain-reactions", causing soil erosion and loss of soil fertility, placing additional stress on an already overburdened and overpopulated landscape (White,1979). Without easy access to fuelwood, impoverished rural households are forced to spend more time gathering wood, to use lower-grade fuels or to spend more money on commercial fuels. At worst, people may be forced to cut down live trees, get by with only the absolute minimum of fuel or move to areas where energy fuel supplies are adequate.

2.5. Energy Resource Distribution in South Africa

Further insight into the factors causing the energy use patterns particular to underdeveloped areas can be gleaned from examining the broader national picture of energy resource distribution and consumption in South Africa. What emerges is clear. There is neither a "shortage" of energy resources nor a "crisis" in supply in the country as a whole. The lack of adequate and affordable energy supplies in underdeveloped areas is due more to the skewed distribution of the right of access to those resources, essentially a political issue. As will be shown below, a more equitable distribution of energy resources among the whole population would not be constrained by overall availability.

The chart below indicates the proportional contribution of each energy source to the total primary energy consumption in South Africa.

Figure 2.4. Approximate Contributions to Primary Energy Consumption in South Africa in 1984



Source: Eberhard (1988)

Of the primary energy resources utilised in South Africa, coal is by far the most prominent due to the country's large exploitable reserves and the fact that this source indirectly contributes to most of the electricity generated, to the demands of heavy industry and to a significant amount of synthetic fuel manufacture. Second to coal is oil, widely used as a transport fuel, and almost totally imported. Biomass, consisting of wood, bagasse, dung, crop residues and wood wastes provide a substantial proportion of the country's total energy consumption, and are the fuels making up the primary energy source for perhaps half of the country's population.

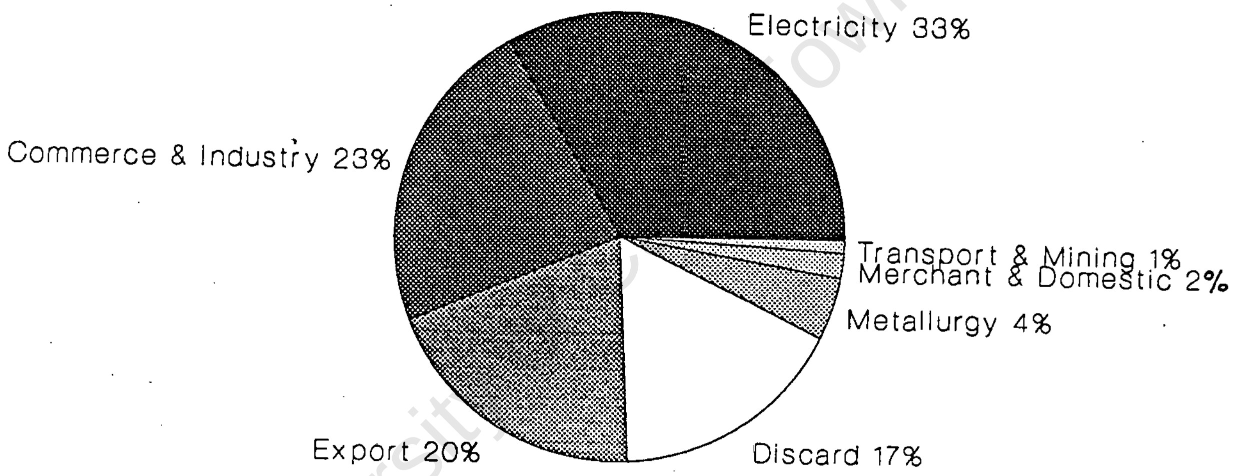
There is very little coherent data with regard to the total consumption of energy in the different energy use sectors but it can be assumed that mainstream industry is the major consumer. As far as household energy consumption is concerned, households in underdeveloped areas, making up about two-thirds of the population, consume a disproportionately small amount of the total national energy budget. This has been estimated at about 275 PJ, only about 14% of total nett energy consumption in South Africa.

2.5.1. Coal

South Africa's recoverable coal reserves were estimated in 1982 to be around 132 000 million tonnes of which roughly half was considered "mineable" (Long,1986:24). South Africa currently ranks 5th in the world bituminous coal production and fourth in total coal exports. Run-of-mine coal production varies slightly from year to year but in 1988 was about 224 million tonnes. Coal is likely to remain the most important primary energy source for the country for some time to come.

The major coal producing fields fall under the ownership and control of the large mining houses although the state has a large influence in pricing policy and export quotas. The pithead coal price is controlled by the state and all coal dealers need authority from the Department of Mineral and Energy Affairs to operate. The wholesale business is dominated by a few large companies but thereafter, the coal destined for the household market is transported and distributed by a large number of formal and informal traders. The end-price is a function of supply/demand, transport costs (distance from pithead to market), and to a large degree, the multi-tiered and relatively inefficient distribution system. The figure below shows the utilisation of coal by different sectors.

Figure 2.5. Coal Utilisation in South Africa in 1988



Source: Dept of Mineral & Energy Affairs (1989)

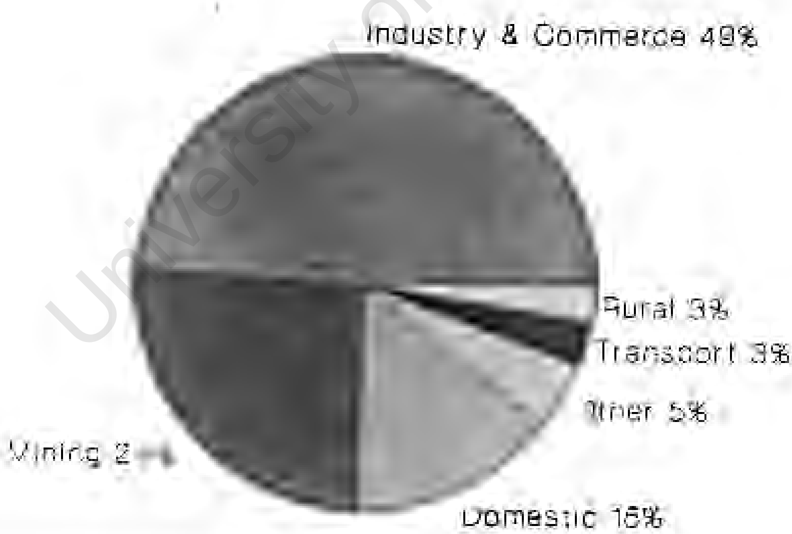
The graph above is slightly misleading in that it is based on mass rather than energy quantities. This is important since not all coal has the same energy content. The large amount of coal "discarded" has a lower-than-average energy content because it is partly the by-product of the benefication of coal bound for export

2.5.2. Electricity

By 1987, the South African Customs Union (South Africa including Botswana, Namibia, Lesotho and Swaziland) had the 14th largest nett installed electricity generating capacity in the world (Eskom,1990:80). The major portion of this capacity could be attributed to Eskom, which in 1987 was also the biggest producer of electricity in Africa, accounting for 47% of the continent's electrical power output, it's closest rival, Egypt, generating a mere 11.5% of Africa's total (Eskom,1990:78). As a country, South Africa has the highest electricity consumption and the highest per capita consumption in Africa. About 90% of the electricity generated locally is from the burning of coal and accounts for approximately one third of all bituminous coal mined in South Africa.

The figure below gives the relative consumption of electricity by different sector, showing the proportion used by households to be substantial but by no means dominant.

Figure 2.6. Electricity Consumption (GWh/annum) by Sector in 1989



<u>Source:</u> Eskom (1990)

The position of South Africa as Africa's largest electricity generator is historically a result of the demands of the mines and associated industries for a cheap power source.

Electricity supply to households has largely been a by-product of this. It is no coincidence that the first city in the country with electric street lighting was Kimberley in 1882, at that time a booming diamond field. Notwithstanding the massive generating capacity of Eskom, and the over 19 000 GWh consumed annually by South African households alone (double the consumption for the whole of Zimbabwe), the supply of electricity for domestic needs in urban areas in South Africa has been concentrated largely in "white" areas, and an estimated two-thirds of the country's population do not have access to electricity in their homes (Eskom,1987). Of these, perhaps half are people living in de facto urban settlements close to existing grid networks (Dingley,1988:12).

In 1986, the Ministry of Constitutional Development and Planning revealed that 86 percent of formal black urban housing was without electricity (SAIRR,1987a:9). Figures released by the Ministry for January 1987 showed that of a total of 252 townships, only 13 were more than 50% electrified. Some 233 were less than 25% electrified including 60 that were completely without electricity (Hansard,1987). Overall, electricity reaches only about 30% of black households in formal townships (Dingley,1990:5).

In the rural areas, large amounts are spent on bringing electricity to white-owned farms. Figures released by Eskom show a allocation of R25 million in 1986 to increase the number of new (white) rural consumers from 7 500 to 8 400, approximately R28 000 per new consumer (SAIRR,1987a:11). In 1987, the allocation was some R 300 million, of which ninety-nine percent was to be spent on supplying about 9 000 white-owned farms, approximately R33 000 per farm (SAIRR,1987b:13). Household consumption in the "homelands" and "national states" is almost negligible, and confined almost entirely to urban centres. In the Transkei, for example, electricity reaches only 2% of the population (Dingley,1990:5).

Dismal though these figures are, they represent only part of the picture. The urban statistics quoted above are limited to proclaimed or "formal" townships in South Africa. There are an estimated 5 million people in "informal" urban areas, needless to say, without electricity, and more than 4 million farm workers on white-owned farms of which about 85% are without electricity (Dingley,1990:6).

It has been estimated that there are, at present, about 4 million unelectrified rural and urban households, and at current population growth rates, increasing at a rate of about 150 000 new households per year (Dingley,1990:10). It has also been estimated that a national programme to electrify all households, spread out over twenty years, would produce an ultimate combined load of about 10 500 MW (Dingley,1990:16). Eskom's generating capacity at the end of 1989, stood at 32 400 MW (excluding Cahora Bassa), while the 1989 peak demand was only 21 900 MW, leaving a reserve capacity of some 10 500 MW (Eskom,1990).

The lack of equitable access to electricity can be attributed to the complex and fragmented supply industry structure, and the fact that the majority of the population, for many years, have had no effective franchise at a national or local level (Dingley,1990:4). South Africa has a overabundance of electricity supply authorities. Besides Eskom, there are over 400 municipal supply undertakings, various Regional Services Councils and Provincial Administrations, as well as the Department of Development Aid, the House of Representatives and individual electricity corporations in the "independent states", all involved in the supply of electricity. This fragmentation, reinforced by the terms in the Electricity Act and the Eskom Act both of 1987, is in stark contrast with the single, rationalised structures seen in most other countries (Dingley,1990:5).

This fragmentation has led to a situation where, although Eskom claims that it is "technically" able to supply electricity to every city, town and village in the country (Leadership,1986:109), it has no effective bureaucratic structure or legislated power to do so. Eskom has thus had it's role confined to the "bulk" supply to large industrial users and mostly white municipalities. In turn, these white municipalities (with a few exceptions) have had little incentive to allocate capital for the electrification of nearby black townships. The result of this fragmentation is that the suppliers responsible for meeting the needs of black households have had neither the financial nor the technical support to make an appreciable impact (Dingley,1990:5).

2.5.3. Petroleum Products

Imported crude oil is the basic feedstock for the manufacture of petroleum products in South Africa with a proportion arising from the conversion of coal. There are three refineries processing crude-oil and the three Sasol coal-to-oil plants in the country, at present the largest coal-to-oil producer in the world.

No volumes of liquid fuels sold in South Africa may be published under the Petroleum Products Act of 1977 but it can be assumed that consumption of petroleum derivatives is mainly accounted for by transportation needs (about 75%). Despite the popularity of paraffin and gas as a household fuel, they currently account for only a small proportion of the total consumption of petroleum products, but can be expected to increase steadily.

Although the paraffin price is currently subsidised, prices of gas and paraffin are ultimately dependent on international oil prices and currency exchange rates.

2.5.4. Wood

Wood resources in South Africa can be divided into five categories namely, indigenous forests, homeland woodlots, commercial plantations, exotic wattle and gum "jungles", and indigenous woodland and shrubland. The table below gives and indication of the areas covered by the first three categories.

Table 2.6. Afforested Areas in South Africa in 1987

TYPE	AREA (ha)
Indigenous forests	165 000
Homeland Woodlots	27 000
Commercial Plantations	1 236 135

Source: Aron et.al.(1989)

According to Aron et.al.(1989:13) indigenous forests and homeland woodlots together contribute less than 1% of the total fuelwood consumption. The large commercial plantations produce about 36 000 thousand m^3 of roundwood annually (projected from Sorfa,1983) and also a substantial amount of wood waste, but contribute little to the total fuelwood consumption. A small but unknown amount is used by households near the wood processing areas. Of the total commercial plantation area, approximately 11% lies inside the borders of "homelands" and "national states"; and of the total area outside the TBVC areas (Transkei, Bophuthatswana, Venda, Ciskei), the majority, approximately 70%, is privately owned. The figure below shows how area is allocated in the commercial plantations.

Figure 2.7. Utilisation of Existing Commercial Plantation Area (1984/85)

Source: Dept of Environmental Affairs (1986)

Wattle and gum "jungles", mostly on white-owned farmland exist in small isolated pockets and are assumed to make a relatively small contribution to the total fuelwood consumption.

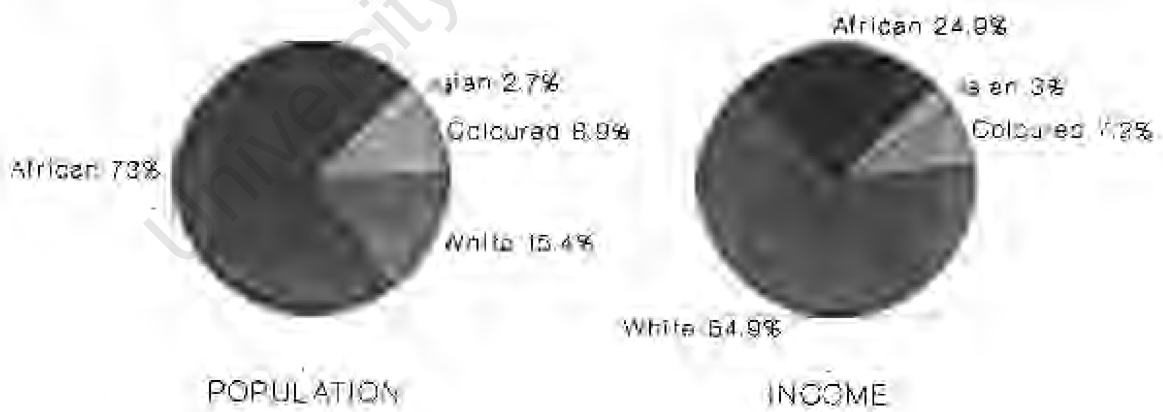
By far the most important contributor to fuelwood use is the naturally occurring woodland and shrubland covering most of the uncultivated land in the "homeland" areas. The wood yield from this source depends on area, tree density, and a number of other factors, and is difficult to quantify. The estimated biomass yield of woodland and shrubland in the "homeland" areas (Aron et.al.1989:26) is about 11,6 million tonnes per annum of which about 5,8 million tonnes is in a form that can be used as fuelwood. As indicated in a previous section, there is evidence that this resource is being depleted at a rate faster than its natural recovery rate, exponentially reducing the overall stock.

2.5.5. Wealth Distribution

Although wealth is not strictly an energy resource, money is the means by which most South Africans gain access to energy appliances and the fuel used to run them. The pattern of wealth distribution in South Africa is highly uneven and steeply skewed towards the white population. The pattern of wealth distribution is discussed here because many of the energy problems facing households in urban and rural underdeveloped areas are a consequence of it.

South Africa exhibits one of the highest degrees of wealth inequality in the world. In 1970, the richest 20% of the South African population owned 75% of the wealth, compared to 62% for Brazil and 39% for the United States (Wilson & Ramphele,1989:18). The racial bias in wealth distribution is demonstrated in the figures below.

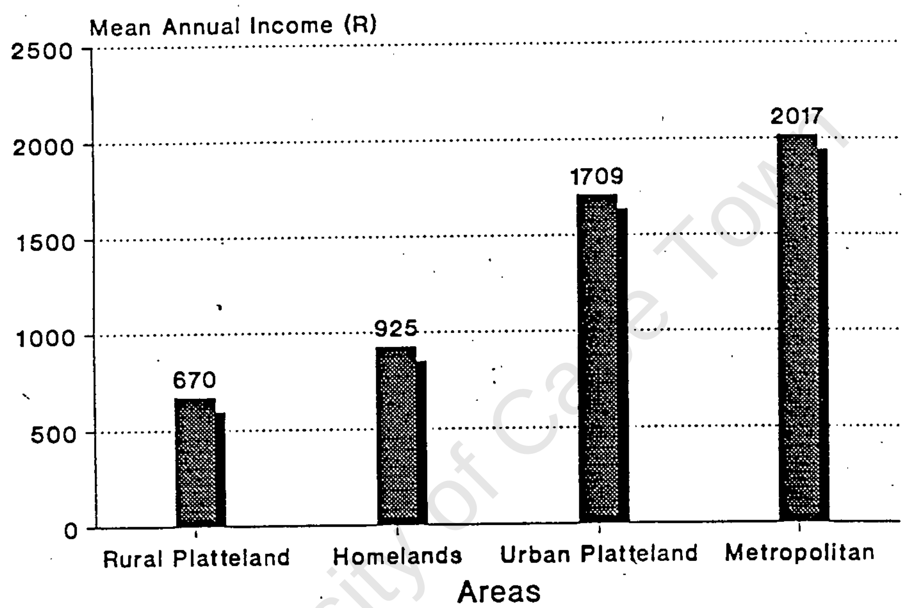
Figure 2.8: Income and Population Distribution by Colour-Caste in South Africa in 1980



<u>Source:</u> Wilson & Ramphele (1989)

The distribution of wealth in this country also has a socio-geographic component with the poorest families living in rural "homelands" and country areas. The figure below gives an indication of this.

Fig 2.9. Mean 1975 Annual Income for Different Areas (Africans only)



Source: Wilson & Ramphele (1989)

2.6. Conclusion

This chapter has illustrated the energy use patterns typical of households in the rural "homelands" and underdeveloped black urban areas, and has explained some of the problems surrounding these patterns. In rural areas, the dependence on fuelwood is increasing the pressure on woodland and forests, with the possibility of wide-scale deforestation and accompanying negative environmental effects. Where all available wood has already been stripped from the land, households on limited budgets are forced to buy wood from traders, or switch to commercial fossil fuels. Further environmental degradation is also caused by the use of marginal fuels such as agricultural wastes, dung, twigs and grasses. In urban areas, the lack of access to cheap electricity forces households to depend chiefly on commercial fossil fuels, particularly paraffin and coal, although in some areas, wood is also bought. These fuels are inefficient and expensive. They are also totally inappropriate to dense urban living conditions, and are the cause of pollution, ill health and fires.

It has been pointed out that energy problems are part of a range of symptoms of underdevelopment; and the lack of access to adequate and affordable energy supplies in underdeveloped areas is not a reflection of the total availability of energy resources in South Africa, but rather of their unfavourable distribution. While the underdeveloped sector consumes a relatively small proportion of South Africa's total consumption, their problems will not be solved by a simple re-allocation of energy resources, or the substitution of one problematic fuel or energy source with another. The situation is somewhat more complex. Energy problems in underdeveloped areas have to be seen in their wider context, and an effective response needs to go further than a simple "technological fix". Accepting the link between energy problems and underdevelopment also means that solutions to the energy problems need not be confined specifically to energy technologies or energy policies. Programmes which for example, allow increased income or lower prices of commercial fuels, alter the ability of households to provide for their energy needs, and also the economic context in which new energy technologies are introduced (Barnett et.al.,1982:3).

Most importantly, energy problems cannot be extracted from problems of poor health services, lack of education, poverty, malnutrition and others. All are symptoms of the same condition and must be addressed as such. Programmes for the eradication of underdevelopment need to address broader economic, social and political issues and an "appropriate energy" strategy should form only part such a programme. In the following chapters, a range of energy technologies with potential application within a development programme will be reviewed.

CHAPTER 3

TECHNOLOGIES FOR HOUSEHOLD ENERGY SUPPLY IN URBAN UNDERDEVELOPED AREAS

3.1. Introduction

Black communities in urban and peri-urban areas are faced with unique energy problems. Since they have little access to either agricultural land or natural woodland, the opportunities for the collection of "free" fuels are minimal. Neither do they enjoy access to cheap electricity, although they may live within kilometers from electric sub-stations. Besides having to cope with burden of poverty, households in these areas are reliant on some of the most costly and least efficient of fuels.

Many "formal" black townships, some which have been in existence for 20 years or more, are still without electricity, and where new townships being built, energy considerations are seen as a low priority. Where townships have been provided with electricity, the lack of any real political voice for these communities has meant little community consultation or participation in the programmes, and consequent mistrust of motives. In addition, the state has increasingly shed its responsibility for providing low-income formal housing in favour of squatter-camp upgrading or site-and-service schemes. In most cases, services provided have been confined to water-points, sewage removal and transport routes. It is in these informal communities that our biggest "development" challenge lies.

As shown in Chapter Two, a typical household in unelectrified urban and peri-urban black areas uses a mix of commercial fuels with paraffin and coal, and in some cases wood, being used extensively. It has also emphasised the inappropriateness of these fuels in an urban environment and the high proportion of the family budget which is used to procure fuels for basic household energy needs. It is clear that there is much room for available technologies to be used to counter some of these problems. This chapter will review some available energy technologies for providing adequate and affordable energy suppplies in black urban areas.

The electrification of urban areas, formal and informal is both desirable and inevitable, and is reviewed first. However, the full electrification of all urban areas will take many years, and there are a number of energy technologies which could be applied either as interim measures, or in concert with electrification, making it more affordable. Photovoltaics, the manufacture of solid fuel from waste, solar water heating and energy efficient design of housing fall into this category, and are each discussed in separate sections in this chapter.

3.2. Grid Electrification

3.2.1. Introduction

Electricity is the "state-of-the-art" in domestic energy supply, and is the energy form all urban households aspire to. It is undoubtedly the most versatile and convenient form of energy for domestic use, and is also clean, safe, and relatively cheap. Despite its numerous advantages over other fuels, electricity for domestic use in South Africa has been concentrated in commercial and industrial centres, white residential areas and white owned farms. Most black urban and peri-urban areas have been denied its benefits.

There are a number of reasons making electricity an appropriate energy supply option for domestic needs in urban and peri-urban areas:

- An argument often used to justify the non-provision of electricity for low-income groups is that they would not be able to afford, and therefore would not support it. Chapter Two, however, has indicated that electricity as an energy source is no more expensive than fossil fuel alternatives. This chapter also discusses cheaper ways of electricity supply and attractive financing schemes.
- Electrification of urban areas would largely eliminate health and safety problems such as burns, fires, etc., associated with burning coal, wood, paraffin and candles in densely populated urban areas. It also has the potential to substantially reduce the severe air pollution in townships on the highveld, where coal is a major domestic fuel. At present, coal-fired power stations generating grid electricity are responsible for much of the air pollution in the eastern Transvaal highveld, and this is a problem that needs urgent attention. The complete electrification of all black townships, however, would add to only a fraction of this.
- Electricity allows the use of a wide range of domestic appliances such as tools, fridges, television, radio etc. It also provides high-quality lighting and improved home security. The "quality" and convenience of electricity make it difficult to be compared with other fuels on a strictly economic basis

- Electricity is the energy standard for all households in the developed metropolitan centres and is generally the preferred energy choice. As incomes and aspirations rise amongst a newly urbanised population, there is no doubt that demand for electricity will increase.

The benefits of grid electrification, however, are not automatic and many electrification schemes in Third World countries have revealed a number of unforeseen problems. International experience in rural areas has shown that electrification alone does not lead to "instant development" and the maximum benefits of electrification are only likely to be realised when electricity is part of a complete development package including other services such as roads, sanitation, health etc. While this is true for rural areas, it is likely to hold for many urban and urban fringe communities in South Africa, where the provision of other basic services may be regarded as more important than electricity supply. Experience in Soweto has also shown that electrification does not lead to an instant change in domestic energy consumption patterns. Households in newly electrified urban areas have considerable sums of money invested in non-electric heating, cooking and lighting appliances, and full utilisation of electricity will not occur until they are able to purchase the new appliances. Electrification may also become unpopular when households find themselves suddenly spending more on energy than they did previously. In newly electrified townships, electricity charges are often very high since the full reticulation costs are being met by the user over a short period. Households unfamiliar with this "new" energy source, may also tend to use more energy than before and not be aware of how to use it efficiently, or, because of the way it is metered and billed, not be able to budget effectively.

While an electrification programme of established townships could be implemented fairly easily, supply to informal areas is much more problematic, and represents a far bigger challenge. Squatter camps, shack areas and site-and-service schemes, despite their informality, are becoming a permanent feature of our urban landscape and the demand for cheap energy from this sector is likely to increase in the future. A number of surveys (Scholtz,1988; Eberhard,1986; Viljoen,1989) have indicated that electricity supply is greatly desired by residents in informal urban areas. Apart from the technical problems in supplying shack areas with electricity (some of which will be discussed below), there are also considerable non-technical constraints, particularly the lack of secure tenure faced by many "squatter" families. The technical problems of supplying shack areas can be overcome without real difficulty, but electrification of these areas cannot proceed until they are given security of tenure. There are many lessons that could be learned from experience in other countries where shack areas have been successfully provided with electricity. A review by Dingley (1988a) on electrification programmes in other "developing" countries provides some interesting case studies.

While it is beyond the scope of this thesis, it is also important to note at this stage, that electricity generation from large coal-fired power stations may not be the best long-term solution to meeting the country's domestic energy requirements. The ecological damage done by acid-rain, caused by sulphur emission from coal burning, has been noted in some parts of Europe, and is already being felt in this country, particularly in the eastern Transvaal (Louw et.al.1990). In addition to this, South Africa's coal reserves, while they are large, are not renewable. Nuclear reactors also use a non-renewable resource and will only change, not reduce, the ecological threat. Centrally generated electricity, also suffers from substantial losses in transmission over large distances, and future electricity price increases may begin to favour smaller local power generating systems using wind, hydro and solar energy. Any long term energy strategy for South Africa will have to take account of these issues.

The remainder of this section will investigate the generation implications, the costs of urban electrification projects and how they can be reduced using new technologies, alternative methods of project financing, and finally, will examine the electrification of Soweto and its results.

3.2.2. Generation Implications

The extra generation capacity required for the connection of all urban households to the national grid can be calculated as the product of the number of households to be electrified and the power demanded per household. Estimates of the number of people without electricity in their homes range between 20 million (Eskom,1987) and 25 million (Dingley,1990:10). Using the higher figure and assuming an average density of 6 people per household, then over 4 million households are at present unelectrified, of which roughly half are urban. A 20-year electrification programme addressing the backlog in both rural and urban areas, and including the additional demand from a growing population of about one million per year, would mean the electrification of some 350 000 new households per year (rural and urban) for the next 20 years (Dingley,1990:10).

The power demanded is usually expressed as the "after-diversity maximum demand" or ADMD, which represents a smoothed figure for household consumption. Dingley (1988b:11), using data from Soweto, Cape Town and the South of Scotland Electricity Board, has estimated the ADMD for black urban areas to be around 2 kW per household. Eskom has quoted 1 000 MW as being sufficient for some 3 million residents in 60 townships (Financial Mail,28/8/87). Assuming a figure of 6 people per household, this reduces to an approximate ADMD of 2 kW per household. Rural households are expected to draw somewhat less, and the ADMD for these areas would be below 1,5 kW per household (Dingley,1988b:12).

Assuming an electrification programme as described above, connecting 350 000 new households per year, the required generating capacity can be calculated. However, because rural households are likely to have a lower ADMD than their urban counterparts, the additional load on the grid would depend not only on the 350 000 new connections per year, but also on the ratio of urban versus rural new connections. Because the electrification of most black urban areas would not require major grid extensions, and because there is more need for electricity in urban areas, it can be assumed the urban electrification would proceed at a faster pace than rural electrification. A 20-year electrification programme with a connection rate of 350 000 new households per year of which 75% are urban (with an ADMD of 2kW per household) and 25% rural (with an ADMD of 1 kW), would demand an additional

612 MW per year for the first 13 years, when all urban areas would be fully electrified, tailing off to roughly half of that as rural electrification is completed. The total load requirements at the end of 20 years would be an additional 10 500 MW above current loads, of which roughly 7 200 MW would be accounted for by urban households. The actual extra generating capacity required by Eskom may differ slightly, depending on how the load pattern of the new consumers influenced the current national load pattern with it's 0900 hours and 1900 hours peaks.

To put this required generating capacity in perspective, at the end of 1989, Eskom had an installed power station capacity of 32 400 MW (excluding Cahora Bassa) and a peak demand on the grid of 21 900 MW (Eskom,1990). The current over-capacity is thus 10 500 MW. The additional annual increase in demand as calculated in the previous paragraph is thus only 3% above the current peak demand. Power supply from the national grid is clearly not a constraint to full urban electrification.

3.2.3. New Technologies and the Costs of Electrification

Since the national grid has already been extended to all major white urban areas, the extension of very high voltage lines to black areas would be minimal. The major costs would thus have to cover the distribution network from incoming bulk supply up to and including the point of metering for each individual consumer. These capital costs are generally recovered from users over time, although sometimes a lump-sum "connection fee" is paid to cover the cost of the electricity meter. House-wiring and new electrical appliances are usually the responsibility of the consumer.

The slow progress in electrification programmes is often attributed by the authorities to the lack of available capital. Given the scale of the problem, it is obvious that large amounts of capital will be required, but this could be reduced, or the extent of electrification broadened if costs are reduced through the application of new technologies and standards. Not only would the reduced capital cost of electrification projects encourage progress, but would also ultimately benefit the consumer, since it is they who carry the financial burden in the end.

Some recent projects give an indication of the installation costs of urban electrification.

- Mohlakeng township, near Randfontein has received a loan of R 8 million to provide electricity to its 3 700 consumers (about R 2 160 per household);
- The electrification of 105 000 houses in Soweto cost around R206 million (about R1 960 per household);
- Eskom has estimated that 3 million residents in 60 townships could be provided with electricity for R 700 million using conventional methods, but this could be reduced to R 348 million using cheaper reticulation methods. The per household cost could thus be reduced from between R2 000 and R3 000 to between R1 000 and R1 500.

Medium and Low Voltage Reticulation

The cost of urban reticulation is dependent on a number of variables including the type of installation, township layout, the designed load level, the cost of materials and labour, and interest rates on loans. There are a number of techniques already identified that, if used instead of the conventional systems, could drastically reduce the cost of new electrification schemes. While 11 kV is considered standard for township HV reticulation, it has been shown that 22 kV reticulation is cheaper except at loads less than about 5 MVA, or for very small transmission distances (Brooking,1988). Costs could also be reduced by moving away from expensive underground cable systems and using using pole-mounted transformers and aerial bundle conductor networks. A typical block of stands can be reticulated at a cost of approximately R1 500 per stand using aerial bundle conductors as opposed to R2 500 per stand using standard underground insulated cable (Eksteen,1990).

Metering and Billing

A report by Scholtz & Dingley (1988) lists different metering and billing systems and gives criteria against which systems can be evaluated. They report three broad categories of metering and billing systems:

- Conventional, in which individual house meters are read periodically, the data processed centrally and bills sent out. Variations on this method include methods of payment, for example, monthly, three- or six-monthly billing etc. There are also possible variations on the way meters are read, whether manually or by remote radio-transmitted devices.

- Non-metering, where only the overall supply to an area is metered. All residents are charged a flat weekly or monthly rate, irrespective of individual consumption, and charges are calculated as a mean of the combined power drawn. Alternatively, individual residents pay a flat rate, and their meters are pre-set to allow a fixed "block" of power per day. The households cannot use more than their allowed number of kilowatt-hours per day, and no credit is given for power not used. This method is rather inflexible and is unfair to frugal households.
- Pre-payment, where coins, plastic tokens or magnetic cards are used to obtain "credit" from the meter. Once this credit has been used up, a new token or card has to be fed in. This method eliminates the need for meter reading and reduce the costs of central accounting, as well as providing the user with an effective method of budgeting.

Conventional metering and billing requires a fairly cheap meter, but a large and expensive infrastructure for regular meter reading, data capturing, posting bills and account-keeping. The Soweto Case Study below has shown that where this is not done properly and efficiently, it can be the source of much dissatisfaction. One of the major perceived problems with conventional metering and billing is the danger that low-income households and first time users may find themselves hard pressed to pay for electricity that has already been used, particularly if bills are not sent regularly and outstanding amounts are compounded. In a survey conducted by Eskom in a recently electrified township near White River (Brooking,1988), residents generally preferred the token operated, pre-payment metering system to the conventional "use-now-pay-later" system because they felt they had more control over their consumption. Dissatisfaction with conventional meters centred around the difficulty in budgeting. Users who received weekly wages, had to pay their electricity bills monthly, and then accounts were only received 30 to 60 days afterwards. Inability to pay then led to the considerable cost and inconvenience of disconnection and reconnection.

The general trend for new electrification projects in low-income areas seems to be in favour of the pre-payment type meter which, apart from allowing households to budget, largely eliminates bad debts. By 1988 about 2 500 prepayment meters had been installed in townships in the Free State and Transvaal (Cape Times,19/8/89), and the system has been gaining in popularity since. The Cape Provincial Administration has recently equipped some 7 000 new houses in Khayelitsha and Mfuleni with meters that operate off pre-paid, magnetic "credit cards". The cards are sold by designated agents and, depending on need or wealth, consumers can buy cards ranging from 20 to 1000 units credit. Pre-payment meters generally include at least, a "units remaining" indicator, an over-current protection switch and earth-leakage protection switch. However, there is still a lot of development work to be done. The meters are rather costly (from R450 to R650 depending on the degree of sophistication), and and the incidence of meter failure is substantial.

One of the strong motivating factors for using pre-payment meters in low-income areas has been the rise in incidence of bad debts, resulting from tampering with meters, vandalism and the use of electricity payment boycotts as a political weapon. In 1988, the Soweto City Council was running up an estimated debt of R20 million a year through political action including the non-payment of electricity, water and rates bills (Financial Mail,4/3/88). The local authorities in many black townships struck by political action are irrecoverably in debt, and in some cases, electricity supply has been cut altogether. The use of pre-payment meters would obviously go some way to eliminating bad debt, but clearly will not eliminate the political problems. Different metering and billing systems may be appropriate for different conditions, but with the meter as the interface between consumer and supply authority, decisions on metering systems should be taken carefully.

<u>Housewiring</u>

Previously, the householder had little say in the way the house is wired because of legislated installation standards. However, it appears that these standards are being reevaluated or relaxed. Conventional housewiring can cost in excess of R1 000, although cheaper innovations such as the use of PVC conduit or not using any conduit but merely plastering the wires directly into the wall, are cheaper and are already being used (Eksteen,1990). House-wiring standards need to be flexible enough to allow households the use of the full range of electrification options, from a single 100 Watt light bulb to a fully lit house with heavy-duty wiring for an electric stove. Wiring systems should allow upgrading that would not mean a complete overhaul if the consumer wished to go from one level of sophistication to the next. While safety should not be compromised, cheaper earth-leakage circuits and insulation standards should be investigated. Electrocution dangers can be reduced by using distribution transformers with two 110V windings in series with an earthed central tap. This allows a 220V supply without the system voltage being more than 110V from earth.

In houses other than brick-and-mortar construction, a different approach is required. One innovative method of household supply, ideal for informal housing, is known as the "Redi-Board". These units have already been installed in some formal houses to reduce the cost of housewiring. The "Redi-Board" consists of metal or plastic box, enclosing a fuse box, three 15-amp plug sockets and a light socket. The unit can be pole- or wall-mounted just inside the house. There is no housewiring as such, and appliances are plugged directly into the board. The "Redi-Board" alone costs in the region of R150 and is often used in conjunction with a pre-payment meter.

<u>Appliances</u>

Once an area has been provided with an electricity supply infrastructure, it is in the interests of the supply authorities to get as many households connected as possible so that their costs can be recovered. One constraint to the popularity of electricity is the high cost of large electrical appliances such as stoves and refrigerators. These are often beyond the means of many lower-income households, and interest rates on standard hire-purchase agreements are unfavourable. Subsidised goods or easier repayment terms would encourage more households to consider electricity as an option. This is not a new idea. In 1930, the Cape Town City Council, eager to attract new consumers, set up and ran a number of "showrooms" where electrical appliances were advertised and compared, and could be purchased on easy terms. The Council also undertook to deliver, install and service the appliances. The scheme ran successfully until the 1960's when it was discontinued (Roohani,1987).

<u>Overall Costs</u>
Using the same assumptions as in Section 3.2.2., a national electrification programme over 20 years would require the connection of approximately 350 000 new houses per year of which maybe 75%, or 263 000 would be urban. Using the cost information above, the cost per connection is:

Reticulation infrastructure using Aerial Bundle Conductors	R1 500
Pre-Payment Meter	R 450
Total excluding housewiring	R1 950
Redi-Board	R 150
Total cost	R2 100

Assuming that a connection fee of around R100 is paid, the recoverable cost would be R2 000 per household. The cost of eliminating the <u>urban</u> backlog alone would thus amount to about R526 million per year for the first 13 years, tailing off to around R150 million per year to satisfy the natural increase in urban consumers. To put these figures in perspective, Eskom's yearly capital expenditure is just over R 4 000 million (Eskom,1990), and the cost of urban electrification would thus account for an additional 13% of this figure. While this seems a small proportion of Eskom's expenditure, it is nevertheless, a large sum of money which has to be raised on the capital market and repaid at going interest rates.

3.2.4. The Financing of Electrification Projects

In comparison to rural electrification, urban projects should be able to pay for themselves because costs are cheaper per unit household, and urban households are also generally more affluent. Nevertheless, low-income households may find it difficult to cope with paying for their electricity infrastructure on top of the normal charge for power consumed. Alternative methods of recovering costs need to be looked at. Dingley (1988c:2) has identified a number of alternative approaches to financing new electrification projects.

- A surcharge could be placed on the kWh unit price of the electricity sold to the new consumers. This would make electricity expensive and would possibly discourage consumption, particularly for high power use such as cooking and heating. Electricity would become among the most expensive energy options for the sector that can least afford it. This would also mean that "old" consumers (in areas where the infrastructure is paid for), and "new" consumers, could be paying vastly different rates for essentially the same service. This could be a major cause of dissatisfaction. Calculating the correct value of the surcharge would also be difficult, since unit consumption varies among individual consumers.
- The cost could be recovered by means of a monthly levy payable by the consumer in addition to but separate from the normal charge per kWh unit consumed. This is the conventional method of recovering capital but for new consumers the repayment can be prohibitively high, particularly when new electrical appliances also have to be bought. This capital redemption method has been use in the case of the Soweto Electrification Project (reviewed later) and has lead to much dissatisfaction. It is possible to reduce the "shock" somewhat by making the initial payments small but then increasing them over a long-term period of repayment, say 20 years.
- The cost to new consumers could be wholly or partly subsidised by the distributing authority and recovered through a levy on consumers nationwide, or a higher unit price charged across the board by Eskom. In 1989, Eskom sold over 134 300 million kWh units of electricity for the average price of 6.90 c/kWh (Eskom,1990:4). Full subsidisation of the estimated R 525 million per year needed for urban electrification (see section 3.2.3. above) would effectively raise the average electricity price to 7.29 c/kWh, a mere 0.39 c/kW increase, which is

considerably less than the 0.6 c/kWh inflationary increase in average price between 1988 and 1989.

- A capital fund for new projects could be established and subsidised by the state, drawing revenue directly from the national budget. However politically unpopular this measure might be, the increase in tax would be almost unnoticeable. The estimated R 525 million per year needed for urban electrification alone is just 0.75% of the government's 1990 budgetted expenditure figure of R70 billion.

In the section 3.2.3. above, the annual cost of a national electrification programme for urban areas of R 525 million has been compared to Eskom's present expenditure on fixed assets of around R 4 000 million. While it is a reasonably small addition, it will still be paid for by the consumers in the end, and the success of urban electrification in raising standards of living, reducing domestic use of fossil fuel and satisfying basic energy needs will depend largely on whether electricity can be made affordable to all.

3.2.5. Soweto: An Urban Electrification Case Study

Introduction

The electrification of Greater Soweto (pop. 1,8 million), a "black township" south of Johannesburg, was started in June 1979 and completed about six years later. Prior to the project, about 20 percent of the houses in greater Soweto had access to electricity, but house wiring was inadequate, and the electrical system overloaded. In the event, these houses were completely rewired, requiring the electrification, virtually from scratch, of some 101 000 houses. Major installations included 37 km of 132 kV lines, nearly 5 000 km of underground cable, 5 major sub-stations, 940 mini-substations, 11 000 low voltage distribution cubicles and the complete wiring of all houses. The total cost was more than R 224 million (Hansard,1987).

The Soweto electrification scheme is an interesting case study in that it was one of the first major township electrification schemes in this country and was presented initially as something of a showcase for township electrification schemes. It also draws out a number of lessons for future projects in that the initial motivation for the project was arguably through an attempt to allay political grievances and amass support for local and central government authorities, rather than through a genuine interest in the welfare of the population of Soweto (Planact,1989). Furthermore there is a fairly large base of literature describing the planning, implementation and results of the scheme.

Pre-Electrification Soweto

Prior to the design phase, a number of socio-economic studies were initiated by a research team which included amongst others: consulting engineers, the CSIR, Eskom, municipal undertakings and the National Advisory Committee on Air Pollution. The following aspects were investigated:

i) Expenditure on all types of energy:

A survey of 1250 households in Soweto indicated that people without electricity spent 60% more on domestic energy requirements than those with electricity (van der Spuy,1981).

ii) Household appliances:

Seventy-eight percent of respondents had coal or wood stoves, 68% had a gas or primus stove, 69% had battery driven record players, 95% had non-electric irons, 46% had hand operated sewing machines, 24% had paraffin refrigerators, and 17% had anthracite stoves.

At the time of the survey, 21% of households had access to electricity, but only 7% of households had electric stoves, and just 2% had electric water heaters. Ownership of smaller electrical appliances was more predominant, and 19% had electric irons, 17% electric kettles, 15% electric record players, and 10% had electric hot plates.

Householders without electricity were asked to indicate their choice in purchasing appliances, assuming that full electric power would be available and that electricity cost would not be a deciding factor: 68% indicated that a stove would be their first or second choice, 29% indicated record players/radios, 26% refrigerators, 25% an iron, 20% sewing machines, 15% washing machines, 9% water heaters, and 7% polishers.

The discrepancy between electrical appliances which households would prefer to own after electrification and the actual patterns of ownership among already electrified households is an indication perhaps of the prohibitive cost of the larger appliances.

iii) Ranking of electrification versus other needs:

The survey indicated that residents regarded electrification, along with crime prevention and street lighting, as the most important improvement that could be made to living conditions in Soweto. Electrification was regarded as being more important than better schooling, medical, transport, sanitation and reduced air pollution.

This survey indicated that the electrification of Soweto would be welcomed by residents and would do much to stimulate an improvement in the quality of life of the city. The benefits of electricity were thus seen to be numerous. They included:

- the expectation of lower monthly energy bills;
- a stimulation in commercial trading with the purchase of new appliances and the stocking of refrigerated items such as fresh produce;
- an improvement of the quality of life including better lighting, heating, and the possible use of audio-visual educational material at schools;
- elimination of air pollution; and
- a reduction of crime with the installation of street lighting.

<u>Technical and Financial Aspects</u>

A few years after completion of the project, a comprehensive review was commissioned by the Foundation for Research and Development under the National

Programme for Energy Research. Details of the project as finally implemented; and an analysis of the effects of the scheme are comprehensively detailed in the study undertaken by Gervais (1987). All page references below, unless otherwise indicated, are attributed to this source.

Regarding the completed project, reticulation consisted of a national grid connection to a 135kV closed ring, feeding 11kV secondary rings in turn supplying low-voltage 400V underground radial feeders. Distribution kiosks, located at various points along the low-voltage lines, each fed from 8 to 16 houses via undergroung cables. The kWh meters for each house were located inside the distribution kiosks. Streetlighting on a separate system was also included in the project.

A "high-tech" consumer energy management system was designed to include:

- automatic load shedding from geysers at the grid's peak demand hours;
- automatic remote kWh meter reading for each consumer;
- remote termination or reinstatement of consumers power supply; and
- automatic computerised billing of consumer accounts.

The facilities as designed were built into the project but so far have never been utilised. Load shedding of geysers is done through a separate radio controlled system (p33).

The report discussed the distribution system in detail and concluded that the design was technically sound although a number of improvements could have been made through more thorough pre-project research and planning (p64). In particular, the cost of the reticulation system and housewiring could have been reduced by applying standards more appropriate to a project of this sort.

There is a degree of confusion as to the final cost of the project. Information available suggests that the total capital cost of the project was between R204 and R206 million with an additional capitalised interest of R24 million which due to delays had grown to R74 million at the eventual completion of the project. Debt repayment has been complicated by the Soweto councils virtual bankruptcy because of a prolonged rent and rates boycott. A fairly accurate breakdown of the cost excluding the capitalised interest portion is given below in terms of cost per stand:

Distribution	
- 132kV subs, 11kV lines & 11 kV subs	R 220
- 11kV & 400V reticulation	R 1 380
- control & supervisory Equipment	R 20
Supply Total	R 1 620
Housewiring	R 414
Total Cost per stand	R 2 034

Post-Electrification Soweto

In spite of the impressive nature of the undertaking, the evidence suggests that the electrification of Soweto has not been completely successful in terms of its original objective of replacing wood, coal and paraffin with a cheap reliable and acceptable household energy supply. Despite electrification these fuels continue to be used in large quantities. Air pollution in Soweto is still a problem and residents are clearly ambivalent towards this "new" energy source. However, according to a Soweto city council official, the demand for electricity has been rising steadily since electrification. Peak demand in the township in 1986 was some 208 megawatts. The 1987 figure was 246 megawatts, an increase of about 19 percent (SAIRR,1987:13). Most of this is probably due to the connection of new consumers, rather than an overall increase in consumption.

The report by Gervais (1987) also surveyed electricity use, appliance ownership and attitudes among residents of the newly-electrified Soweto homes. Some details are discussed below:

- Of the total sample population (all electrified), 65% still used wood and coal, primarily for cooking, but also for space and water heating (pp88). It was shown that 80% used their coal or wood stoves in summer as well as winter (pp89). Other fuels such as paraffin, LPG, candles and batteries were also still in use although to a lesser extent[1]. A large number of Soweto homes do not have ceilings, and were perceived to be "very hot" in summer and "very cold" in winter. Clearly in such a situation, many residents would think twice before throwing out their old coal or wood stoves, which serve an important function as space heaters.

- While for major energy requirements such as cooking and heating, wood and coal were still used in many households, the ownership of electric appliances, particularly the smaller ones, was fairly high. Of the households studied, 89% owned an electric iron, 87% a kettle, 82% owned either an electric stove or a hot plate, about 78% owned a T.V. set and 76% a refrigerator (pp118). In contrast, only about 39% owned electric water heaters (geysers and urns) (pp96).
- An important indication of the desire to use the benefits of electricity to the full, is indicated by the response to questions about the intention to purchase electric appliances. Appliances that would be purchased within the next 12 months were: an electric bar heater (22%), a video recorder (21%), an electric kettle (17%), and an electric 4-plate stove and oven (16%) (pp121).

Electricity Costs and General Perceptions

At the time of the post-electrification survey, there was evidence to suggest that electrification was not as economically attractive to residents as had originally been argued. Pre-project estimates gave a total capital cost of the project at R150 million and costs to the consumer at 3.5 c/kWh with a capital redemption fee of R3/month

1 This trend is supported by an earlier study in Transvaal urban areas which found that, of the electrified black households surveyed that had electric stoves or hotplates, 70% also had coal stoves which they used primarily for space heating. About 60% of coal stoves in use were conventional rather than the smokeless type - LHA Management Consultants (1982) A Survey of Certain Aspects Relating to Smoke Pollution in Black Urban Areas"

escalating to R17/month over a period of 7 years (MIE,1980). The amount actually paid by consumers comprised of a once-off payment of R 700 for connection to the system and thereafter a monthly charge with three components (p124):

- 6,2 c/kWh of electricity used;
- a R4 basic charge; and
- a capital redemption fee, also known as the "availability fee" of R29 (this was later reduced to R12)

According to a sample of electricity accounts, the average Soweto consumer paying the new capital redemption fee of R29 and using 364 kWh/month would be expected to pay R55-55/month. This translates to an average of 15,3c/kWh, roughly double what Cape Town households were paying at the time (Dingley,1987). Monthly electricity charges were subsequently revised (Planact,1989), and in March 1989 were as follows:

- 7.71 c/kWh of electricity used;
- a R1-29 basic charge; and
- a capital redemption fee of R12.

By comparison, the charge structure in Cape Town in March 1990 included a R6 basic charge and a unit price of 10.47 c/kWh.

A survey on attitudes and perceptions found that the majority of residents seemed to be unhappy about the price they were paying for electricity and there was a large degree of suspicion about the way electricity usage was measured and accounts determined. The survey showed that 70 % of the respondents did not know how their electricity use was measured, and 79 % did not know how their accounts were determined. Consequently, monthly fluctuations in accounts led a large group (46%) to believe that they were in some way being cheated. The majority of respondents (76%) also felt that their monthly bills were higher than the amount they initially expected to pay, and 90% felt that the electricity accounts were unfairly worked out. Although it appears that Soweto residents were paying heavily for their electricity, the costs were actually less than was generally perceived. While the actual monthly electricity bill was below 10% of household income for nearly all residents, the perceived costs varied between 15 to 20 percent of income.

Another cause for unhappiness was the apparent sloppiness in billing consumers and the frequency of un-announced power cuts and disconnections. In some cases, residents did not receive bills on a regular monthly basis, and then when the bill did arrive, they were unable to pay the large amount owing. A survey by Planact (1989) noted that 57% of respondents had been inconvenienced by cuts or disconnections, although it is not clear whether these households had been paying their bills or not. The major criticism allround appeared to be the unexpectedly high cost of electrification. On the positive side, electricity was seen as being convenient, fast, and clean.

The survey by Gervais (1987) also included informal discussions with residents, many of whom expressed dissatisfaction with the lack of community involvement in the planning stages of the electrification project. Residents felt that they had not been fully informed of the implications of electricity supply, and were not consulted in the process. Consequently they lacked commitment and responsibility towards the project. No doubt, dissatisfaction with electricity costs and the lack of involvement and consultation in the scheme were factors contributing to the subsequent non-payment of electricity bills (along with a rent boycott) as a tool of political protest. The debt to the Soweto City Council due to unpaid water and electricity bills and vandalism had reached R 100 million by early 1988, R30 million of which was due to damaged sub-stations and meter boxes. In 1987, some 40 000 residents were disconnected for not paying bills but most of them were able to reconnect themselves illegally causing damage to expensive meter boxes (Financial Mail,4/3/88). Options open to the Soweto councils to combat this situation are narrowing. The Electricity Department has proposed trying out new reinforced meter boxes, a pre-paid token system or as a last resort, simply "pulling out the plug" on non-paying customers.

The Soweto Electrification Project has indicated that large scale electrification of low-income areas is technically feasible but economically and politically very sensitive. A number of actions, among others, if implemented, could have made the project more successful:

- A comprehensive pre-project research into community energy needs and attitudes towards electrification. In particular, the ability and willingness of communities to pay for the service.
- A consumer education programme prior to the project where residents could be informed of the benefits of electricity, the workings of the metering and billing system; as well as how much they would be expected to pay for the service and for new appliances.
- Considering the intricacies of township politics, the project should have been totally divorced from political structures such as black municipal authorities.

3.2.6. Conclusion

The benefits of electricity to urban households have been adequately described and are in any case, largely self-evident to anyone who has lived in a home with electricity. The longer term implications of urban electrification for the development of the country are less obvious and more difficult to quantify, but are nevertheless as important. Not only are the advantages and benefits of electricity obvious on an academic level, but they are also reflected in the demand often expressed by those without access. There is no doubt that by denying electricity to these areas, quality of life expectations are frustrated and poor communities are further impoverished by having to meet the high cost of fuels such as coal, gas, paraffin, candles, and batteries. This can only exacerbate the already deteriorating social and political situation in these areas.

It should be borne in mind however, that electrification of residential areas, for reasons political, economic, health, humanitarian or whatever, will seldom yield "overnight" results. Newly electrified areas will not show a sudden switch in fuel use patterns. Households have considerable sums invested in non-electric appliances, and the switch to electrical appliances, particularly among lower-income groups will be slow. A few years after completion of the massive Soweto electrification project, for example, a survey showed that people were still relying heavily on coal, paraffin and wood, but the desire to accumulate more appliances was clearly there. Electrification should also not be seen as a panacea for all ills arising out of the dismal living conditions characteristic of many black formal and informal urban areas. There are other services such as adequate water supplies, health and education that are desperately needed, and that should be provided prior to, or at least, along with electricity.

This review (and experience in other countries) has shown that while electrification programmes are slow to implement and are very expensive, they are seldom constrained by technology. The two major constraints, which are in a way related, seem to be the lack of sufficient funds for the electrification of black areas, and the lack of an adequate structure for assuming this responsibility. In the first case, it has to be accepted that electrification projects are capital intensive, and that financial returns may be slow. It also has to be accepted that the conventional method of repaying capital expenditure may unfairly burden new low-income consumers, and may inhibit the rapid growth of new consumers, on which project viability depends. If electrification is seen as an essential part of the national economic development, as it is in many countries, then it follows that new electrification projects should be financed from the central budget and subsidised to whatever degree required. Innovative financing schemes could also be developed to ease the initial costs of purchasing a range of electrical appliances. As a further development, electrification could be coupled with an integrated package of energy conservation measures, including better house insulation and possibly solar water heating.

The rapid progress of electrification however, requires the prior creation of a suitable structure to control funds and direct the implementation of an urban electrification programme. The electricity supply industry in South Africa at present, is characterised by a plethora of institutions involved in electricity supply to domestic users. Responsibility for electricity supply is at its most complicated in some black areas where the black local authorities are dependent on neighbouring white municipalities for all their services. While Eskom seems willing to tackle it's "electricity for all" objective, it is unable to break the inertia of a fragmented and inefficient local government structure. The rationalisation of the country's electricity supply industry is thus essential to the progress of electrification in underdeveloped areas. Basically what is required is a single authority responsible for policy matters and the distribution of funds; a single bulk supplier, such as Eskom; and a small number of subsidiary authorities responsible for distribution in their respective areas. Experience in a number of other countries offers comparative models which could be used as a starting point for the development of a suitable South African model.

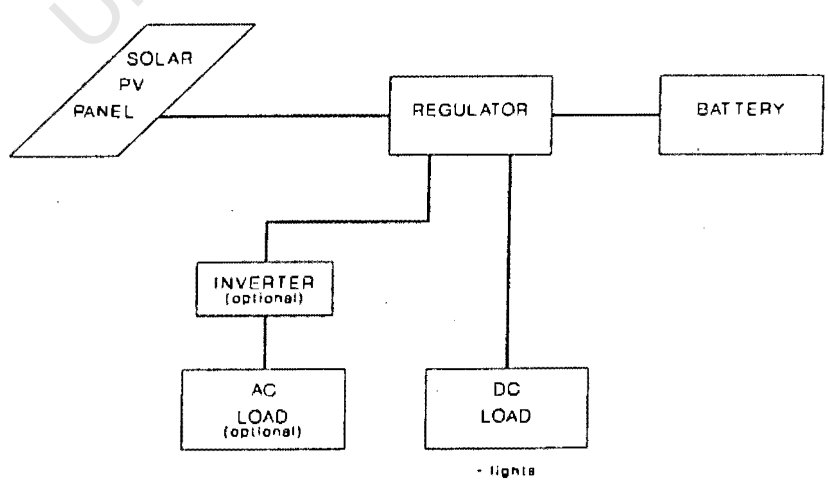
Provided that a suitable structure for directing electrification, and suitable methods of raising and repaying capital can be found, it should not be difficult to provide electricity to the millions in formal areas. The biggest challenge lies in bringing electricity to the ever-growing informal urban areas. Here, technology <u>is</u> a constraint and suitable ways of providing electricity will have to be developed and improved as electrification of informal areas progresses. Another major challenge lies in finding ways of including communities in the process of electrification. The Soweto project, for example, proceeded at a rapid pace with very little community involvement or education throughout the scheme. A subsequent survey revealed that many residents complained of not being fully aware of the implications (particularly regarding cost) of township electrification, and many felt that they were being robbed or cheated in some way. Much of this dissatisfaction, resistance to electricity and distrust of electricity authorities could have been averted with a more sympathetic approach.

Electricity for households is the most sought after and desired energy form, and access to it can have a major impact on people's quality and way of life. This section has shown that the provision of electricity for every household, or "one person, one volt" is not an impossibly high goal. It is in fact fairly easily within our grasp.

One of the earliest applications for photovoltaic cells, developed in the late 1950s, was to provide power for orbiting satellites. The small demand and the highly complex procedure for the manufacture of photovoltaic cells, which will not be discussed here, made them extremely expensive. Demand grew relatively slowly, and by 1980, the world-wide production totalled only 3 MW. Since then, the manufacture of PV cells has grown rapidly, matched inversely by a drop in their retail price. By 1986, world-wide production had risen to 27 MW through the development of better and more economical production methods (Sinclair,1989:55).

Despite the advanced technology required to manufacture the actual cells, photovoltaic electricity supply is ideally suited to low-power household electricity demand since it is simple, clean, non-polluting, involves no moving parts or high temperature fluids, and is relatively maintenance free. A typical home lighting PV system would consist of an exterior mounted solar panel, a 12V deep-discharge lead/acid battery, a miniature solid state regulator, and for AC current requirements, an optional DC/AC inverter. The load could be any combination of low-power appliances such as lighting TV or radio. A diagrammatic sketch of the layout is shown below:

Figure 3.3.1. A Typical Home Lighting PV System



Solar panels are available in different sizes and are rated, according to their output, in peak watts (Wp), which is the amount of power (watts) produced by the panel under standard conditions of 1000 W/m^2 solar radiation and a temperature of 25°C. A typical panel size for home power use would be in the region of 40 to 80 Wp (depending on sunshine and load requirements), corresponding to a physical panel size around 0.5 to 1.0 m^2 respectively. Panels of the future are expected to be more efficient in converting sunshine and will thus be smaller and cheaper. The panel array would typically be mounted on the roof or in some other sunny spot, and aligned facing north (in the southern hemisphere) at an angle giving maximum solar radiation. The optimum angle is calculated according to local solar radiation conditions and load requirements.

Batteries are used in the system to store the energy collected over sunny periods so that electricity supply is available at night and on sunless days. The size and number of batteries, and their configuration (12 or 24 V) depends on the application. A typical household PV system would require one or more 12 V batteries rated at about 80 Amp-hour. The battery/ies are usually a lead-acid type, but are designed specifically for the deep and frequent charge/discharge cycles of a PV system. Car batteries are generally unsuitable since they are designed for rapid, shallow discharge/recharge cycles, and would give reduced lifetimes. Low maintenance sealed batteries, although more expensive, are ideally suited for home power use. Other batteries besides the lead-acid type can also be used although they are more expensive. The battery is the only relatively expensive item that needs regular replacement, but if well cared for should last up to 8 years.

The **regulator** controls the flow of current from the panel to the battery and to the load, and also acts as a battery protection device. If the battery is fully charged, current from the panel is diverted. If the battery is flat, current is prevented from being drawn. Excessive charge or discharge of the battery can cause it permanent damage.

An **inverter** (optional) is used to transform the direct current (DC) from the battery or the panel to alternating current (AC) if required. AC loads should be avoided where possible since a substantial power loss occurs across the inverter. Small TVs, music centres and lighting units using DC are now generally available.

The **load** consists of the appliances powered by the system. There are some electronic appliances such as video machines, TVs, and refrigerators, specially designed for PV installations, that use minimal DC current. Fluorescent tubes are suitable for lighting since they provide good light at minimal current. Halogen lights, while fairly expensive, are also suitable and are available in standard 12 or 24 volt rating.

3.3.3. Photovoltaic Economics

Possibly the biggest drawback of PV systems for low-income users is the high initial cost involved. Paraffin and candles, while not a cheap source of light, involve only a small capital investment. The fuels can be bought in small quantities when required or when they can be afforded. Photovoltaic systems bought on credit would still only be available to relatively well-off families who could guarantee regular monthly payments over a number of years. However, even at current prices, a system which would power a television set and a couple of lights may be purchased for roughly the same price as a new coal burning stove.

A PV system is relatively expensive, but the panels have a very long lifetime (up to 20 years), and the whole system has low maintenance and running costs. Battery replacement is one of the major running costs, but given proper, the batteries should last between 5 and 10 years. To make any meaningful comparison with other energy sources, a cost benefit analysis has to discount these capital payments over the typical life of such a system and thus reflect the true cost per unit energy, in, for example, cents per kWh. This "levelised annual cost" is sensitive to a number of key variables, namely:

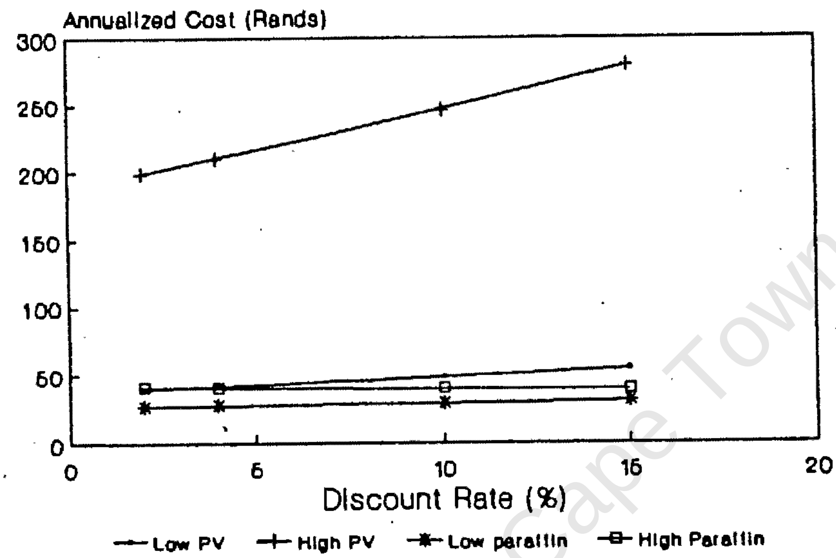
- Module cost: dependent on the type of module, module production costs and the rand/dollar exchange rate.

- Insolation levels: the lower the insolation, the larger the surface area required and thus more expensive the module.
- Discount rates: they are important since PV systems characteristically require high initial capital payments but have a long lifetime.
- Battery type and cost: longer lasting, more reliable batteries are also generally more expensive.
- System sizing: the requirements of the user will influence the size of the module/battery combination. Oversizing will push up the cost per unit energy without any additional benefit, while an undersized system will be cheaper but will cause power loss at times. There are a number of methods to size systems each with varying degrees of accuracy (Borchers,1989).

Of all the components making up a PV home-power system, it is the solar panel, or module, that is the most costly item, and its price will thus have the greatest influence on the economics of such installations. The selling price of PV modules has dropped drastically in recent years and is expected to drop even further. However, since all photovoltaic cells are imported into South Africa, local prices are highly dependent on exchange rates and actually increased in 1983 from around R 11/Wp to around R 19/Wp following the drop in the value of the Rand (Sinclair,1989:72).

As a viable low-power household electricity source, a PV system supplying lighting and perhaps a small electrical appliance would have to be competitive with the presently used mix of paraffin lamps, candles, car batteries and petrol generators. Sinclair (1989:183) provides a comparison of PV lighting with paraffin lighting and concludes that at present prices, paraffin lighting is more economical. The quality of PV lighting is however unquestionably greater.

Figure 3.3.2. A Cost Comparison on PV vs Paraffin for Lighting

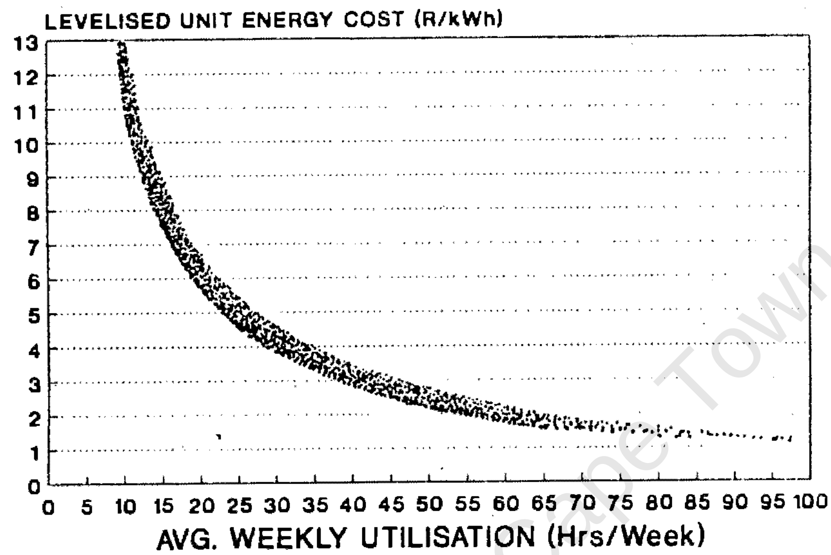


<u>Source:</u> Sinclair (1989:183)

The quality of lighting from candles is comparatively poor and very expensive, costing in the region of 295 c/MJ (Eberhard,1984:6). The cost of energy from a car battery on the other hand, can run as high as 600 c/kWh. In comparison with small petrol generators (1 to 5 kW), PV systems would be almost always competitive.

The high cost of the solar panels means that the cost per unit of energy generated is very sensitive the size of the system. Accurate estimation of the user requirements and an appropriate sizing philosophy is therefore crucial to the competitiveness of home-power PV systems. The effect of system oversizing on the unit energy cost is dramatically illustrated in the graph below. In this case, the installation was for a photovoltaic powered educational TV-video system for remote schools, designed to provide power for a 50 hour/week usage rate. The graph shows the rapid increase in the cost of the power as the utilisation decreases or oversizing increases.

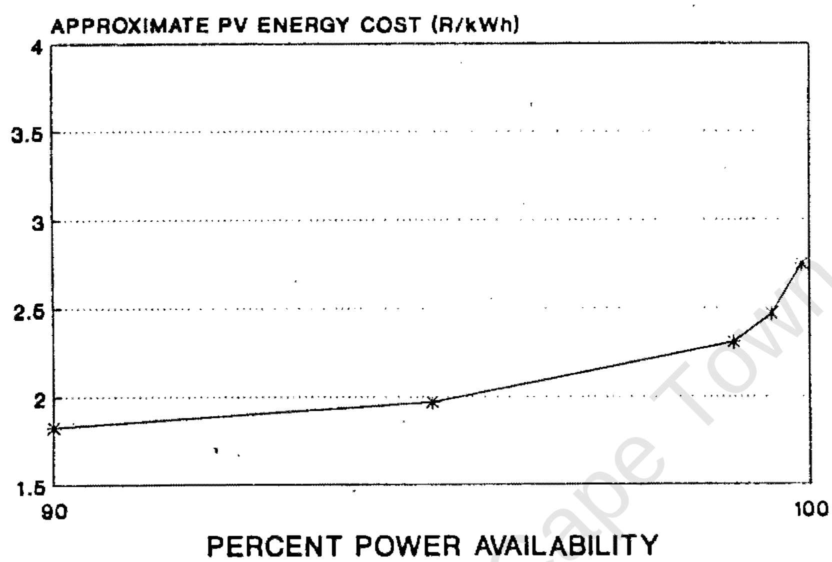
Figure 3.3.3. The Cost Effects of PV Oversizing



Source: Cowan (1989)

The high initial cost of PV systems and their cost-sensitivity to oversizing requires that the design and marketing of such systems for low-income household applications needs to move away from 100% power availability designs to those which are more appropriate in terms of cost and application for low-income households. Such an approach does not imply an inferior system, but rather careful and innovative design of appropriate technology. Families who have experienced only candles and paraffin lights would probably accept the few days a year when unusually bad weather would cause the system to be inoperative. As indicated in the graph, the difference in cost between a 100% power availability and 95% availability system is substantial.

Figure 3.3.4. Power Cost vs Power Availability for a PV Unit



Source: Borchers (1989)

3.3.4. Uitsig: A Case Study

A demonstration PV system was installed in a house in Uitsig, an urban sub-economic area located on the Cape Flats, some 18 km east of Cape Town near Elsies River. The area is an un-electrified and was originally established as a transit settlement, although some families have been there for as long as ten years. The system was installed and monitored by the Energy Research Institute, University of Cape Town (see Muller,1988 and Sinclair,1989).

The house consisted of four rooms with an outside toilet and tap, and had a floor area of 36 m^2. The house was orientated east-west and had an A-frame roof. Installation consisted of:

- Two ARCO M75 PV panels, rated at 47 Wp each.
- One Solar Sciences 10A 12V DC Voltage regulator with boost/float charging and undervoltage load shedding.

- One 90 amp-hour Raylite Leisure Pack battery.
- Four 11W Comlite fluorescent tubes with ballasts, one to a room, and a socket for power to a TV or music centre.

In sizing the panels and calculating the optimum tilt angle, local solar radiation data (D.F. Malan Airport) for the "worst month" was used, i.e. that month in which the ratio of insolation to projected load is lowest, and was calculated as 14 MJ/m^2 at a tilt of 54^o to horizontal. The load was estimated at 148 Wh/day for summer and 236 Wh/day for winter. This sizing gave a projected power output of 94 Wp with a battery storage requirement of 114 amp-hours. The regulator allowed the battery voltage to "float" at 13,8 V cutting of at a high of 14,5 V. The regulator also provided battery protection by disconnecting the load if the battery voltage dropped below 11,5 V, reconnecting at a voltage of 12,1 V. The panels were mounted on the roof at a fixed angle and the regulator and battery were enclosed in a cabinet inside one of the rooms.

During the year of monitoring (1987), the actual load drawn was about 20% greater than the design estimate, and the actual solar radiation was less than predicted. Nevertheless, the system worked satisfactorily and loss of power was experienced only three times in the year when the regulator disconnected the load in order to protect the battery. However, problems were experienced with almost all the components bar the PV panels. All the light fittings had to be replaced, the regulator burned out and the battery electrolyte levels were not maintained, causing a shortened battery life.

There are two factors highlighted in this case study. Firstly, the importance of accurately predicting the load, and secondly, the need for reliable components. While load estimation, design and sizing requires good engineering judgment, the reliability of components has been improved with modular electronics, allowing maintenance and repair by relatively unskilled people. Battery maintenance can also be minimised by the use of sealed, "maintenance free" batteries.

3.3.5. Conclusion

The frequency of candle, paraffin and battery use in underdeveloped urban areas, indicates a definite demand for low-power electricity supply which could be ideally met by photovoltaic systems. However, photovoltaics in the urban context should not be seen as a substitute for full electrification. They are confined to low-power applications and have a high initial capital cost, which may set them beyond the reach of many households. Even if they did become cheaper, it is unlikely that the demand for full electrification would decrease to any great degree. In practice, grid electrification will not be supplied to all urban households for many years to come, and PVs could in the interim free households from inappropriate energy sources such as paraffin, candles and car batteries.

3.4. Briquetted Solid Fuel

3.4.1. Introduction

For households in urban areas without grid electricity supply, the major energy problem remains an affordable, convenient fuel for high energy consumption activities such as cooking, water and space heating. A potential cooking and heating fuel alternative to paraffin, coal and gas, is waste-derived briquetted solid fuel. Certain industries in South African produce large amounts of high-energy waste product in a form which is not immediately usable, but which could successfully be reconstituted into a suitable fuel through a process of compacting or briquetting. Such fuel, given the right economic conditions, could be cheaper than any of the commercial fuels presently used. A further advantage is that this fuel could be made smokeless, alleviating some of the pollution problems experienced with the use of coal and wood.

The potential contribution of waste-derived fuels to the national energy supply is substantial. Petrie & Eberhard (1989) estimate a potential annual energy yield of 224 petajoules from this source, representing about 70% of the total energy requirements of the underdeveloped sector in South Africa.

The viability of a waste derived solid fuel programme depends largely on the economics of manufacturing the briquettes. Since the transport of unprocessed waste would be uneconomical, only cases where there is a high degree of centralisation of the waste material can be considered. It is envisaged that production of the fuel would take place close to the waste source, with the briquetted fuel finding its way to consumers through established fuel distribution networks. Three high-energy waste sources have been identified that suit the above criteria:

- Both the mining and processing of coal create large deposits of waste in the form of fines and high-ash discard.
- The timber processing and paper/pulp industries produce large quantities of wood waste from debarking and sawmilling.
- The sugar industry produces waste bagasse in considerable quantities.

The extent and location of these waste stocks and their feasibility as a feedstock for briquetted fuel is discussed in more detail below. The bulk of this information has been taken from Petrie & Eberhard (1989), unless otherwise indicated.

3.4.2. The Extent of Waste Stock

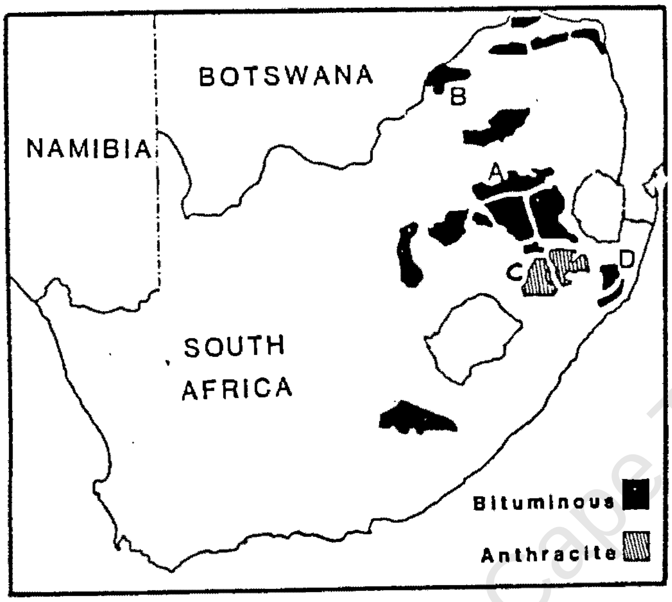
Coal

There was in 1986 a stockpile of nearly 300 million tonnes of coal waste, growing at the rate of more than 48 million tonnes per annum (Grobbelaar,1986). The waste consists of fines (duff coal) and high ash coals. The high-ash discards are a by-product of the coal benefication process which is required before South African coal is suitable for export. These discards are produced at a rate of 40 million tonnes per year, and form 60% of the total coal waste stockpile. The discard is mainly bituminous in the size range 12 - 100 mm diameter, has a calorific content anywhere between 4 and 24 MJ/kg and a 2 to 8 percent sulphur content. The remaining 100 million tonnes of stockpile is made up of coal which is too small to be burnt in conventional combustion equipment (particle size usually less than 6mm). It is a by-product of the mining and milling processes and is produced at a rate of 4,5 million tonnes per year. The fine coal consists of bituminous and anthracitic coal and has a much greater energy content, between 22 and 31 MJ/kg, and a fairly low ash and sulphur content. The higher density and calorific value make fine coals the most valuable and likely source for waste derived fuels.

For briquetted fuel to be comparable to coal, only waste with a calorific value in excess of 20 MJ/kg can be considered as a suitable feedstock. Some 9,09 million tonnes of coal waste of above 20 MJ/kg is produced each year with a potential of over 180 PJ/year should it all be made available for briquetting.

The logistics of briquetted fuel production make it essential that the waste stocks be geographically localised. Four main areas can be identified as having potentially important stocks of discard and fine coal. These are respectively the Witbank, Waterberg, Nongoma and Kliprivier-Utrecht-Vryheid (KUV) coalfields. Together their waste coal produced and stockpiled represents 95% of the total in South Africa.

Figure 3.4.1. The Location of Major Coalfields in South Africa



A - WITBANK.
B - WATERBERG.
C - KUV.
D - NONGOMA.

Source: Petrie & Eberhard (1989).

Wood

The only significant producers of wood waste are the large-scale industries associated with the commercial timber plantations. It has been estimated by Sorfa (1983) that the surplus sawdust and small wood residues currently available from timber processing industries amount to over 300 000 m^3 per annum. Taking into account the respective densities of hard- and softwoods, this data translates to a possible energy contribution of 7 PJ per year.

There are three steps in the wood processing industry which generate waste:

- Tree harvesting leaves about 45% of the nett log volume in the forest in the form of roots, stumps, branches and tops. Utilisation of these would have to take into account possible ecological damage and the high cost involved in gathering this dispersed resource.

- Primary roundwood processing industries including sawmilling, pulp, paper and board manufacture, mining and pole timber production, and plywood and veneer manufacture. The type of industry and the wood used, dictate to a large extent the amount of waste produced. These industries are usually located close to the commercial plantations.
- Secondary wood processing industries manufacturing finished wood products are located over a wider area. Waste generation from these sources is dispersed an difficult to quantify.

The most viable source of wood waste is that from the primary processing industries. However, a significant amount of this waste is used by the industries for boiler fuel and some is also sold for use in the manufacture of chipboard, wood-cement composite and paper. These industries are located near to the forestry belt, which occurs mostly down the length of the eastern regions of South Africa (the eastern Transvaal escarpment and Natal) with some isolated spots in the south and south-west of the country.

Bagasse

Of all agricultural residues, it is only sugar-cane bagasse that displays any potential as fuel since the processing of sugar, of which the bagasse is a residue, is highly centralised at a number of large mills on the Natal coastal belt, the south-eastern Transvaal lowveld and lowveld Swaziland.

Bagasse is already used fairly extensively as a boiler fuel in the sugar industry and some is sold to pulp and paper mills nearby. It is estimated that about 2 million tonnes of bagasse (50% moisture) could be made available for energy considerations outside of the mills. This translates to some 14 PJ per year (Williams & Eberhard,1988). However, it is possible that much of this will be taken up by paper mills and ethanol conversion plants in the future.

3.4.3. The Production of Briquetted Solid Fuels

There are basically three methods of producing briquettes, namely:

- high-pressure compaction (1000 kg/cm^2);
- medium-pressure compaction with heating; and
- low-pressure compaction with addition of a binder material.

In addition, briquettes may be compressed into single "pellets", or continuously extruded and then cut. The choice of process depends largely on economic factors and on the material used as a feedstock. High-pressure compaction requires expensive machinery, while low-pressure techniques require cheaper less sophisticated equipment, but make use of a binder which adds to the cost of materials. There are a number of "appropriate technology" briquetting and peletising processes involving human or animal power which can be operated on a very small scale. However, these are more suited to compacting of agricultural waste in rural areas. In urban areas, municipal waste could also be compacted for fuel but the separation of waste by hand into combustible and non-combustible would an arduous and unpleasant task. There has been a considerable interest in area and a number of "enthusiasts" have experimented with ways of briquetting or peletising household wastes. However there are only few established production facilities and no viable market.

There are a number of suitable binder materials for low-pressure briquetting, among others, molasses, tar and wood resin. One South African company[1] manufactures a 25 MJ/kg product from anthracite fines and molasses. Another[2] produces a briquette from coal dust and wood or paper waste in a 30% coal - 70% wood or paper mixture.

1 Harrington Sales, PO Box 11096, Cape Town

2 Umlilo Ciskei (Pty) Ltd. with the parent company being Ru-Korrel, PO Box 195, Malmesbury, 7300

The starches in the paper and wood make a binder unnecessary. The fuel has the advantage of being slow burning and relatively smokeless, and faster burning fuels may be obtained by increasing the paper proportion. The calorific value of the briquettes is 18 - 20 MJ/kg.

3.4.4. Solid Fuel Economics

Any realistic strategy for large-scale centralised conversion of waste to fuel for domestic use would need to be financially attractive to the suppliers of the raw-material and the producers of the finished product, as well as providing fuel cheap enough to compete with presently used solid fuels. The retail price of waste derived fuels would vary, depending on the type and cost of the raw material, cost of binder material (if used), fixed production costs and the transport distance to the consumer. The selling price of briquetted fuel obviously has to be competitive with similar fuels already on the market, since apart from the possibility of being made smokeless, it has no other advantages to the end-user.

Raw material cost can vary from the case where the producer would pay the consumer to remove the waste, to where the waste is sold as a valuable by-product. In the wood and cane industry, waste is usually discounted at zero cost. A proportion of the waste is absorbed within the industry, typically for use as boiler fuel, with some mills operating their boilers at a low efficiency simply to reduce stockpiles. With coal wastes, the situation is made more complex by the variability of types of waste. Much of the waste at collieries still has a high calorific value and the industry is reluctant to discount their stockpiles in the hope that there will be a lucrative market for the waste at some future date. Fine coal could find application in fluidised bed furnaces, but this technology has not yet made much impact locally and stocks of fine discards are likely to keep growing. Despite this, most collieries still seek a price proportional to the energy content and this would clearly make a briquetted fuel uneconomic. A more realistic price for both low- and high-energy waste coal could be derived from the cost of dumping/stockpiling plus the reclamation and a percentage profit.

Production costs vary with the type of process and the feedstock used. A more detailed discussion on costs associated with different production methods are given in Petrie & Eberhard (1989). The two most economically attractive cases appears to be binderless high-pressure briquetting of coal waste and pelletisation of wood waste.

The siting of production facilities is particularly critical as a major portion of the final price paid by the end-user could be due to transport costs.

3.4.5. Conclusion

Waste coal, timber and bagasse waste are all potential raw-materials for a briquetted fuel industry although the latter two would contribute to less than 10% of the potential total energy supply. The introduction of a briquetted fuel programme should therefore be concentrated on coal-based fuels.

The vast quantities of coal fines presently dumped or stockpiled represents a valuable national resource that is being wasted. Because of the possibility that there will be some future more lucrative market for high-grade waste, the coal mining industry is unwilling to sell its stockpiles. Much of the waste is being destroyed by the spontaneous combustion of dumps, adding to the air pollution problems in coal mining areas, and unless some form of legislative pressure is brought to bear on the coal mining industry, the present stockpiling will continue. While the sale of coal waste for production of briquetted solid fuels is not likely to be as attractive to the coal mining industry as a potential industrial market, the immediate conversion of the waste into a usable fuel would be a much more efficient method of managing a valuable resource than is presently the case.

The stocks of discard and duff coal are situated in four relatively small geographic areas, linked to the major conurbations by an extensive road and rail network. It is envisaged that a number of production plants would operate near to the waste dumps, and that the final product would be distributed to consumers via the existing retail infra-structure much in the same way as coal.

3.5. Solar Water Heating

3.5.1. Introduction

Energy for water heating is an important requirement in any household whether for washing clothes and utensils, or for personal hygiene. While electricity may be the preferred fuel for household use, it is not necessarily the cheapest or most efficient energy source for heating water. The same can be said for fossil fuels. Solar water heating (SWH) would seem to be an obvious option for low-income households in that it utilises a "free" energy source, is safe, clean, and the technology involved is relatively simple and well understood. It is not proposed that solar water heating completely replace other fuels, but rather that it should form an important part of an overall "energy package" for low-income urban households.

While hot water is needed for numerous activities in the household, this need is not always fully met in underdeveloped areas where cold water may be used instead. Despite the difficulty in estimating hot water needs, and the general lack of data on consumption patterns, it can be assumed that the need for hot water in urban households forms a substantial proportion of total domestic water needs. A study by McLean et.al.(1985) gave a mean hot water consumption of between 13 and 59 litres/person/day for low-income black households in townships on the Highveld. Consumption is clearly a function of availability, since the higher figure was recorded for more affluent households with electric geysers. Consumption figures for higher-income areas gives an indication of hot water usage not limited by availability. Total water consumption in higher income areas is between 200 and 300 l/person/day, and assuming that about 50% of this is for washing or personal hygiene, gives a hot water consumption of 100 to 150 l/person/day.

The amount of energy required to satisfy hot water needs varies greatly depending on the efficiency of the heating methods used and the initial and final temperatures of the water. In middle-income households where geysers are used, about half of the total monthly electricity consumption goes towards heating water (McLean et.al.(1985).

Where there is no electric geyser, less hot water may be consumed although less efficient methods may be used to heat it.

Solar water heating thus has the potential to significantly reduce electricity bills of households with electric geysers as well as providing a greater availability of hot water to households without electricity.

Solar water heating devices of all types do however have a number of intrinsic disadvantages:

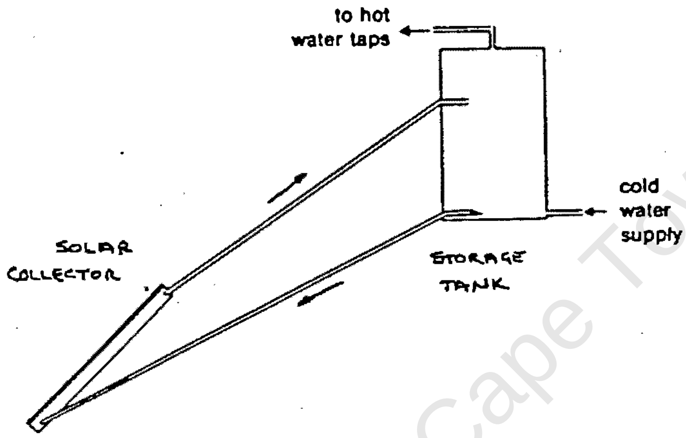
- The solar energy reaching the earth is very diffuse requiring large collector areas, making the technology expensive. The annual 24 hour global solar radiation average for South Africa is approximately 220 W/m^2 (Muhlenbruch-Tegin,1988).
- Solar energy is an unreliable source and is highly dependent on weather and seasonal variations.
- Solar energy is at best, only available for a few hours during the day and heat lost from the system at night can be significant.

Despite this, solar water heating is the most established solar energy technology. There exists a wealth of information and research data on the subject, and the principles of using solar energy directly for heating water are well understood. It remains potentially one of the most viable uses of solar energy.

3.5.2. Solar Water Heating Technology

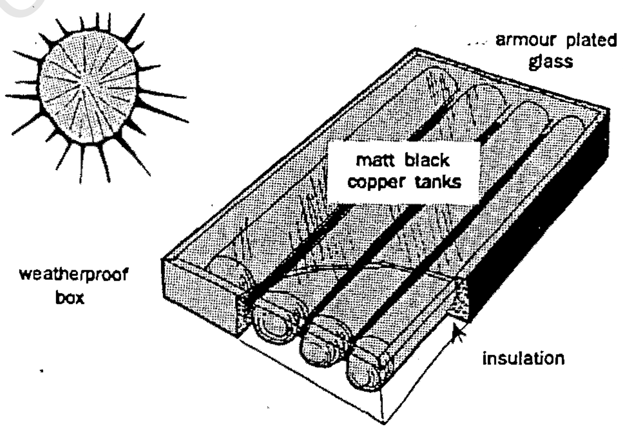
Presently available solar water heating systems, according to Cawood (1988) can be grouped in three basic configurations outlined below:

Figure 3.5.1. Separate collector-storage SWH Unit



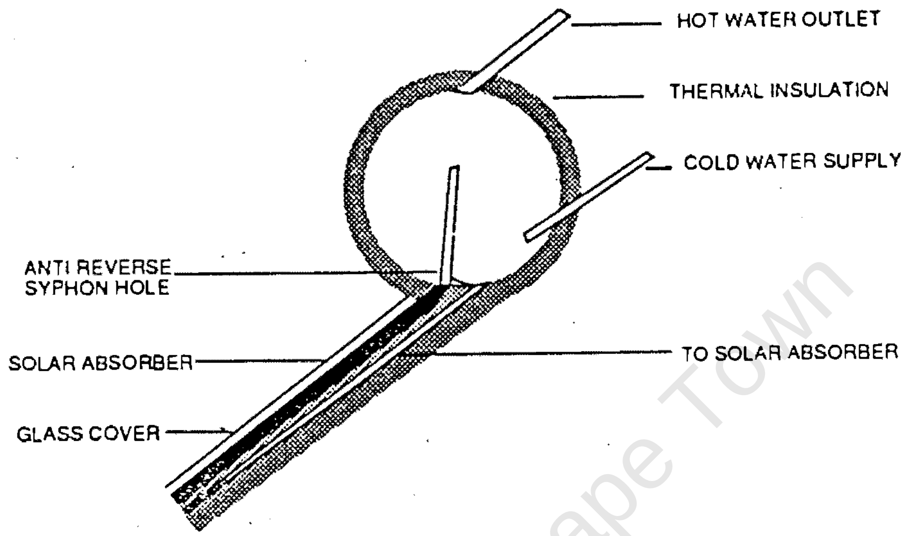
The collector panels heat the water which is then thermo-syphoned or pumped to a separate insulated storage tank. This is a fairly sophisticated system and, while it is the most efficient, it is also the most costly.

Figure 3.5.2. Integral collector-storage SWH Unit



The collector is made of large-diameter piping which also acts as the storage tank. The simplicity of this design makes it the cheapest of all. It's biggest problem is the substantial loss of heat at night or on cold, cloudy days. The system is really only suitable for supplying hot water in the afternoons and early evenings.

Figure 3.5.3. Close-coupled collector-storage SWH Unit



The storage is mounted directly above the collector panels in close proximity, the whole system appearing as a single unit. The compactness of the unit makes it cheaper but also introduces possible problems with reverse-syphoning.

All three systems can be used as "stand alone" water heaters or as pre-heaters and supplements for existing geyser systems. Alternatively, the storage tanks of the separate and close-coupled units can be fitted with electrical heating elements operated manually or by thermostat.

A technical constraint to the adoption of commercially marketed SWH units is that they all require a piped water source. This effectively cuts out a large section of the urban population in formal and informal housing. There are however, a variety of methods which do not require piped water, and which can be made cheaply or from scrap material. A discussion on these methods, some of which may have application in urban areas can be found in the next chapter, in the section on solar water heating in rural areas.

3.5.3. Economics of Solar Water Heaters

There are three possible situations where a householder may consider the purchase of a solar water heater.

- Where an electric geyser exists, a solar water heater can be installed to cut electricity bills.
- In a new, or recently electrified home, the choice can be made between an electric geyser only, a stand-alone SWH or a small electric geyser with SWH backup.
- Where there is no electricity, the house holder may wish to install a SHW instead of heating water on the stove.

Considering the first case, it can be assumed that the existing electric geyser produces sufficient hot water for the family's needs and that the solar water heater is purchased because it will save enough in electricity bills to cover the initial capital cost within an acceptable time period. Assuming further that:

- A low-income household uses about 6 000 kWh per year.
- The electric geyser accounts for roughly half the electricity bill.
- The solar fraction (that fraction of the total hot water provided by the solar heater) can be assumed at around 50% (this is highly dependent on usage patterns, solar radiation levels and temperatures).

Cash saved in the first year is a product of the total electricity consumed, the fraction used for heating water, the electricity unit price and the solar fraction, thus:
Annual Saving = (6 000 kWh)*(0,50)*(0,50)*(R/kWh)

Assuming also a 15% electricity price escalation and a 20% interest rate per annum, the "break-even" cost of a SWH unit can be calculated. The highest price that can be paid for a SWH unit for it to break-even over ten years (although manufacturers seldom offer guarantees beyond about five years) is given for a range of electricity prices in the table below.

Table 3.5.1. Amortised Solar Water Heater Break-Even Costs for a Middle-Income Household

INITIAL ELECTRICITY PRICE (c/kWh)	MAXIMUM CAPITAL OUTLAY (R)
10	1250
15	1870
20	2500

Although a more complete analysis would take account of varying solar radiation levels, system efficiencies and unit size, the table above gives a rough indication of the price range where solar water heaters would become economically competitive. Prices of SWH units range from R1 000 to R3 500 depending on the size and sophistication of the system. Electricity price for domestic users in 1990 were around 15 c/kWh. Clearly only the simpler and cheaper units are competitive, and then only just so.

In the second situation, where there is electricity but no electric geyser, a solar water heating system becomes more attractive since it must be compared with the purchase of a new electric geyser. However, with present SWH prices there is no evidence to suggest that a solar water heater with sufficient capacity to be used as the sole water heating system is a cheaper option than an electric geyser. A more likely option would be a small, relatively cheap SWH unit in combination with a small electric water heater, particularly where electricity is very expensive and average solar radiation levels are high.

In the third case, where there is no electricity at all, the capital cost of a SWH will have to be compared to the cost of heating water using coal, wood or some other fuel. An accurate economic analysis in this situation is difficult but it can be assumed that solar water heating would be a viable alternative to inefficient use of coal stoves or wood fires. However, households not able to afford electricity would not be able to afford the capital costs of a SWH unit unless very favorable terms could be arranged for them.

With present price structures solar water heating is not, in most cases, an economically viable option. This is due to a combination of the unrealistically high capital cost of commercial systems and the relatively low unit cost of electricity. It is interesting to note that, in a survey of 100 solar water heater owners conducted in 1980/81 by the National Building Research Institute, it was found that, while the majority of respondents thought that their SWHs would save electricity, a large number (40%) also mentioned patriotic sentiment as an added reason for their purchase. Only 20% were actually able to prove electricity savings by comparing past electricity bills (Stander & Basson,1982).

State-initiated incentives to promote the use of solar water heating is one way to stimulate the market. In Italy, USA and Germany, the government provides tax incentives or subsidies to encourage the installation of SWH systems (Cawood,1981). In Israel, some 60% of dwellings have functional solar water heaters and the installation of a solar water heater is now mandatory in all new homes. There is no such policy in South Africa. Sterne (1985), in examining the macroeconomic implications of a hypothetical 50% market penetration of SWH unit sales by the year 2000, found that the South African national electricity consumption could be reduced by 9 500 GWh per annum. This is equivalent to about 7% of the power "sold" by Eskom in 1989 and more than the output of the Koeberg nuclear power station (Eskom,1990). Widescale adoption of solar water heaters and the savings in electricity could lead to substantial savings in coal reserves, water, foreign exchange and create much needed employment.

In underdeveloped urban areas, the dependence of households on fossil fuels is in part due to their inability to afford more sophisticated energy sources or technologies that may in the long run, save money. If solar water heating, essentially a very simple technology, is to make any meaningful difference to the energy consumption patterns and quality of life of underdeveloped households, ways of making the technology economically more attractive will have to be found.

3.5.4. Solar Water Heater Market Trends in South Africa

The marketing thrust in the SWH industry in South Africa has until now, been directed almost exclusively at the upper-income sector and has focussed on electricity saving, rather than on providing hot water where there is no electricity. Until very recently with the development of cheaper solar water heater units, the lower-income market has been completely ignored.

Domestic applications of solar water heating comprise the major part of the market. In 1977, domestic applications accounted for 46% of the total SWH sales and this fraction had risen to about 90% by 1984. Since their introduction commercially in South Africa, sales of solar water heaters have risen steeply, although there has not been much growth since 1983. The table below gives an indication of the sales trend.

Table 3.5.2. Estimated Annual Sales Volumes of Domestic Solar Water Heaters in South Africa

YEAR	SALES VOLUME (sq.m)	PERCENT INCREASE
1979	12 000	—
1980	16 660	38
1981	19 250	16
1982	21 100	10
1983	24 920	18
1984	18 150	-67

Source: Stassen (1988)

The estimated turnover for the domestic sales volume in 1984 was of the order of R11 million representing about 2,7 million completed domestic units and an estimated market penetration of around 1,3 percent (Stassen,1988). This rather poor market performance is not the result of any technical deficiency of South Africa solar water heaters, but rather a result of their economics. Under present conditions of low electricity cost and high initial capital cost, solar water heating is not economically favourable. Stassen (1988) provides three reasons for the high capital costs, namely:

- rapidly escalating production costs affecting local manufacturers;
- the exchange rates and import charges which inflate imported SWH or SWH components; and
- marketing practices where independent agents, rather than manufacturers, sell and install, thus controlling the retail prices.

Arising from the above-mentioned marketing practices is an inordinately high marketing cost which is recovered in the inflated retail price. Sterne (1985) gives an estimated breakdown of costs for a 1,2 m^2 integral unit and a 4 m^2 (two panel) collector-storage system shown in the table below.

Table 3.5.3. Estimated Cost Breakdown for Locally Manufactured Solar Water Heaters

ALLOCATION	INTEGRAL UNIT (1985 Rands)	TWO COMPONENT SYSTEM (1985 Rands)
Manufacture	250	800
Installation	250	300
Marketing	650	1 750
Sales Tax	50	150
Retail Price (installed)	1 200	3 000

<u>Source:</u> Sterne (1985)

Three independent surveys of the SWH market conducted in 1985 showed that the average markup for locally produced SWH units from the manufacturer to installed retail price was in the order of 220 to 240%, while the markup for imported units was around 150 - 160% (Stassen,1988). A noticeable trend following the declining sales volumes in recent years, is a "shake-down" in the SWH market, with a substantial number of companies closing operations and more manufacturers opting to market their product directly.

3.5.5. The NBRI Integral Solar Water Heater: A Case Study

The assumption that high capital costs prevented many low-income householders from adopting solar water heaters, provided the motivation for the first serious attempt at developing and assessing a solar water heater specifically for low-income households in South Africa. The project was conducted by the National Building Research Institute (NBRI) of the CSIR in three black townships in the PWV area and is summarised in reports by McLean et.al.(1985) and Basson (1988). The information presented below is taken largely from the above two publications. It is unfortunate that there was no investigation beforehand to determine needs in the low-income sector around which a SWH could be designed and tested. Instead, the project tested a device that had already been designed to fit a perceived gap in the lower price range end of the solar water heater market. Nevertheless, the project is significant in that it was the first SWH research study in South Africa to seriously address the energy problems in low-income urban households. The essentially "new" technology was evaluated not only economically but also in relation to user attitudes.

The survey included a selected group of 160 households in the black townships of Mamelodi, Daveton and Klipspruit, all within the Pretoria-Witwatersrand-Vereeniging area. Although classified as low-income, all the houses in the study were electrified, which biased the sample towards the wealthier sector of the community. In addition, all the houses in the study had existing piped water supply, considered a prerequisite for this type of solar water heater. Households were divided into three groups, namely:

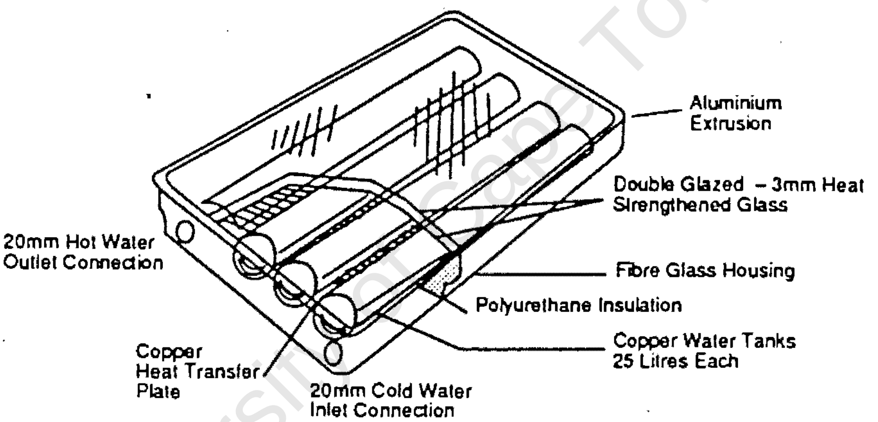
- a control group, using existing electrical geyser systems only;
- a group using the integral SWH as a pre-heaters to their existing electrical geyser; and
- a group with the integral SWH as their only fixed water heating system.

Water and electricity meters were connected to all houses in the survey, and the specially designed low-cost 100 litre capacity integral SWH units were installed in 94 houses. The units were donated by the manufacturers and were installed free of charge.

SWH Unit Characteristics

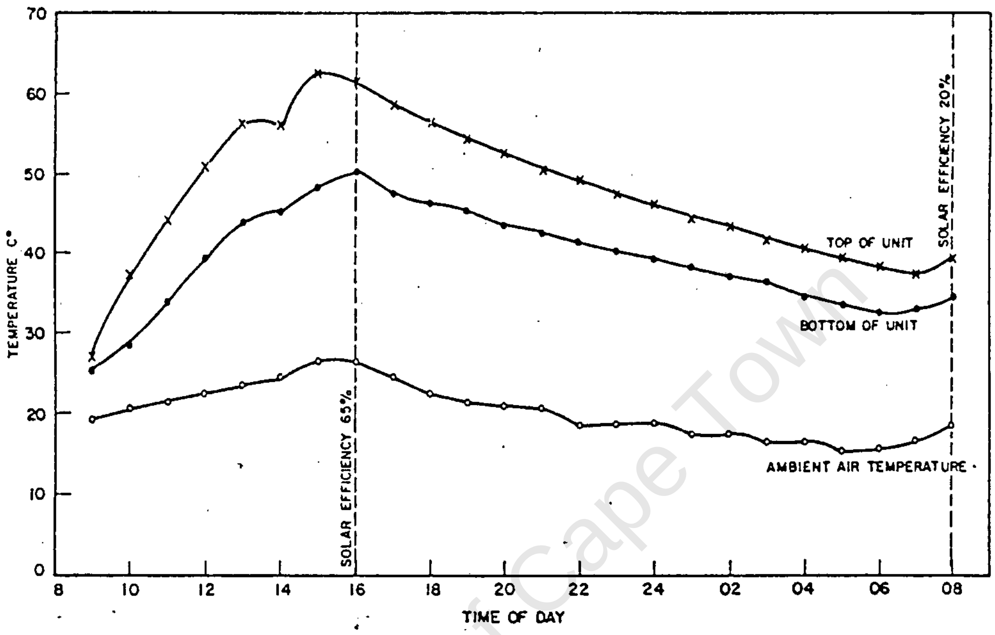
The solar water heaters installed were commercially built units based on a prototype developed at the NBRI in 1978. The unit consists of a combined collector and storage tank with a matt black absorbing surface, installed inside an insulated container and covered with one or two sheets of clear glass.

Figure 3.5.4. The NBRI Integral Solar Water Heater Unit



The unit was tested extensively in the laboratory to determine solar efficiency, durability and resistance to freezing, hail damage and water penetration. Solar efficiency trials on the integral SWH unit were favourable and showed that on a sunny day, warm water (+40°C) would be available from as early as 11h00, reaching a peak of up to 60°C around 15h00 and, presuming no water was drawn off, could stay warm until about midnight.

Figure 3.5.5. Time-Temperature Profile for the ISWH



Because of the large mass of water stored in the collector, the unit suffered from a high degree of heat loss when the sun was not shining or when ambient temperatures were low. The heater was thus not able to deliver hot water in the early mornings. This is a short-comming of all integral-type solar water heaters.

<u>Consumption Patterns</u>

Once the SWH systems were installed, the electricity and hot water consumption in each group was monitored. Average figures are presented in the table below.

Table 3.5.4. Mean Monthly Hot Water Consumption in Low-Income Black Electrified Households

HOT WATER SYSTEM	SUMMER WINTER (s/w)	HOT WATER TEMPERATURE (Deg C)	HOT WATER CONSUMPTION (l/cap/month)
ISWH Only	s	variable	570
	w	variable	480
Electric Geyser	s	61	1350
	w	60	1620
Geyser and ISWH	s	59	1360
	w	59	1470

Source: McLean et.al.(1985)

Not surprisingly, the data shows a good correlation between hot water consumption and availability. While there is not much difference in consumption between the geyser-only and the geyser-plus-ISWH groups, consumption of hot water by households without electric geysers is markedly lower, probably due to the inconvenience and inefficiency of heating water on the stove. It is also possibly due to the "geyser-less" group representing the lower income end of the electrified households and thus being generally more frugal with their fuel use. Summer/winter differences are fairly significant. Households with geysers have a higher consumption in winter (8-20%), while those without have a 16% lower consumption. Again this is indicative of both the inconvenience and inefficiency of heating water on the stove, as well as the possible different economic circumstances of those without electric geysers.

The hot water consumption figures are reflected in the electricity consumption as recorded in the different groups and shown in the table below:

Table 3.5.5. Mean Monthly Electricity Consumption in Low-Income Black Electrified Households

HOT WATER SYSTEM	TOTAL (kWh)	GEYSER (kWh)	GEYSER (%)
ISWH Only	332	0	0
Electric Geyser	817	373	46
Geyser and ISWH	748	284	37

Source: McLean et.al.(1985)

In houses using electric geysers, 37-46% of the mean electricity consumption was used for providing hot water. These households also used roughly double the electricity consumed by households without electric geysers. Respondents in the latter group replied that they obtained hot water by boiling on stoves and in kettles, but often using fuels such as paraffin and coal. The high proportion of electrical energy drawn by the geysers demonstrates the scope for a technology such as solar water heating to significantly reduce household energy bills.

Energy Savings

As an electric geyser pre-heater, the performance of the ISWHs was disappointing. The mean solar fraction, indicating the proportion of the total hot water used that is supplied by the solar heater alone, was very low. Under laboratory conditions it was a satisfactory 0,74 with a peak evening consumption. However, in the trials it ranged between 0.12 and 0.26 and was thought to be due to the high demand for hot water in the early mornings when the solar heater performance was at its poorest. In some cases the performance of the SWH/geyser combination units was worse than straight geysers because of overnight heat losses from the exposed SWH unit.

An examination of monthly energy costs showed that the highest bills were recorded in households with electric geysers only, probably because of the latter groups' higher average income and greater use of hot water. Households with neither electric geyser nor SWH had the next highest bills, followed by those with electric geysers coupled to integral SWH units, and finally households with stand-alone integral SWH units only.

The electricity saving brought about by solar heating was not very impressive. For the control group with unaided electric geysers, the mean monthly electricity consumption was between 720 kWh and 920 kWh. Where there was a solar water heater fitted as a pre-heater, the consumption varied between 680 kWh and 790 kWh per month. The monthly saving, between 60 and 100 kWh, was disappointingly low. Some installations even produced a "negative saving" in winter, possibly because of the heat lost from the panel/storage tank during the night, the same reasons causing the low solar fraction. Translated into financial terms, the average <u>annual</u> amount saved (1984 rands) was a paltry R48 in Mamelodi, R37 in Davyton and R31 in Klipspruit.

It is interesting to note that although the energy expenditure for households without any fixed water heaters at all was about 15 percent lower than those with electric geysers, the hot water consumption was about 40 percent lower. This indicates that the use of stoves and kettles for warming water is both less efficient and more expensive.

An rough analysis shows that the integral SWH units installed in the project did not present an immediately attractive option for pre-heating an existing electric geyser. The average annual electricity saving for the three townships was 896 kWh/yr, and the mean electricity price, 4.3 c/kWh. Assuming a ten year lifespan of the SWH unit, a 15% escalation of electricity price and a 20% interest rate, a SWH unit under these circumstances would have to cost less than R320 for it to be economically attractive.

The purchase price of commercially sold integral SWH units ($1.3m^2$ area and 100 litre capacity) in 1985 was between R 835 and R 1 350 (Stassen,1988). It is unlikely therefore that an integral SWH unit would "pay for itself" through electricity savings.

Attitudes

The social aspect of the study showed that the major portion of the hot water consumed was for personal hygiene (from 35% to 75%) and that preference and habit dictated the highest consumption to occur in the early mornings before 10h00. The poor performance of the integral solar water heaters in the early mornings was perceived by users as a major disadvantage. However, it could not be conclusively established whether or not those with existing electric geysers would be willing to adapt their living habits to conform to the times when hot water was available from the solar heaters.

In households previously without a fixed water heating system, residents seemed willing to adapt their usage habits to fit in with the availability of the hot water supply from the integral SWHs, and were generally pleased with the units. It should however be remembered that the units were provided free of charge. Where dissatisfaction was expressed, it seemed mainly to be due to the non-realisation of expected electricity savings from the hot water contribution of the SWHs. Problems were also caused by periodic drops in water pressure, particularly in Mamelodi, which sometimes prevented water from being drawn from the units. In all, 18% of respondents in the group with electric geysers plus ISWHs indicated that the hot water was "seldom sufficient". Savings in electricity bills were mostly too small to be noticed over a monthly period by the residents. This was aggravated by a general lack of understanding of the three-monthly metering system used by the local authorities. There was also some suspicion as to the motives of the study, some residents believing that the installation of SWHs would delay the full electrification of their townships.

While reaction to the use of the solar water heaters was in general positive, the acquisition of other appliances such as stoves, TVs and refrigerators above a hot water supply (solar or otherwise) was regarded as being more important. On being shown the cost advantages of the ISWH over an electric heater, the highest preference for owning an ISWH came from the group with previously no fixed water heater. Those with both an electric geyser and a ISWH expressed the lowest preference.

3.5.6. Conclusion

The energy costs for heating water consume a sizable proportion of a family's income and the use of a solar water heater has potential to save the user significant amount of money. Considering that solar water heating is a well understood, well researched and simple technology, popular in many European countries, it has a surprisingly poor market performance in South Africa. The major reason for this appears to be economic - the electricity price is too low, and the SWH unit price is too high. The rapid rate of urbanisation means that a large potential market for solar water heaters will inevitably be created wherever electricity is not supplied or, if it is available, where households are contemplating the purchase a water heating system. The price of electricity will inevitably rise in the future but this, in relation the general inflation rate, will probably not be much. The potential for widescale adoption of solar water heating thus depends more than anything, on a reduction of the retail price of SWH units, either through the manufacturers and retailers reducing their costs/profits, or through a state assisted programme of subsidisation.

A solution to the high cost of conventional solar water heaters was seen in the development of the integral solar water heater (ISWH). However the field trials in three black townships (reviewed above) showed it to be unsuitable. Here the fault seems to lie with the design, which does not allow for warm water in the early morning when it is in greatest demand. The SWH industry is now putting considerable effort into reducing the retail price of the more promising close-coupled unit. Many of these units would also allow retro-fitting with electric heating elements obviating the need for a separate electric geyser. However, to date no comparative performance or cost studies have been done with a low-cost close-coupled SWH design.

Even if solar water heating was found to be economically viable, the initial capital cost may still bar low-income households from the market. The initial cost could be reduced by financing under reasonable terms. Future low-cost housing schemes, for example, could include a "built-in" SWH system which would add only a small fraction to the overall building costs. Another obstacle to the wide-scale adoption of SWH technology in underdeveloped areas, apart from the economics, is the lack of piped water in the homes of the growing "informal" urban sector, and it is doubtful whether this situation will improve in the short term.

Also to be borne in mind is the fear of some township residents, noted in the NBRI survey, that the use of solar water heaters could give the authorities an excuse to delay the full electrification of their townships. Residents may also be wary of purchasing SWH units, rather keeping the capital available for buying electrical appliances if there is the possibility of future electrification. Solar water heaters will not be widely accepted if they are seen as a "substitute" for full electrification of townships. However, we have seen that the use of electric geysers can substantially increase electricity bills and serious thought should be give to promoting solar water heating as a viable, money-saving alternative to electric geysers.

3.6. Energy Efficient Housing

3.6.1. Introduction

After cooking and the provision of hot water, space heating constitutes the next most important energy intensive requirement for households in urban areas. Space heating requirements in underdeveloped urban areas are generally met through the burning of wood, coal and paraffin, which are costly and are associated with pollution, fire and health problems. Fuel consumption could be reduced by improved thermal design of housing in these areas.

The provision of low-cost urban housing for black people in South Africa has for a long time been the responsibility of a government unable or unwilling to adequately fund housing projects. The general approach has thus been to provide "four walls and a roof" at the lowest cost possible with scant regard to the thermal comfort of the occupants or the need for fuel conservation. Houses have been poorly orientated, and the choice of building materials, lack of ceilings, interior doors or any insulation has meant that most structures experience high heat losses and therefore require high heating (or cooling) loads to maintain comfort levels. In squatter camps and site-and-service schemes, households suffer even more since they either cannot afford decent building materials; or live under threat of removal and are unwilling to construct permanent, well-built structures. Those who can least afford it spend a disproportionate amount of their income on energy for thermal comfort.

The potential for improved thermal designs to make a significant impact is evident when looking at the current situation regarding urban housing for the low-income black households. The formal housing stock in black urban areas, excluding "homelands", in 1985 was estimated at about 446 000 units, a situation which satisfied less than half of the real demand. Demographic projections show the demand exceeding 3 million housing units by the year 2000 (NBRI,1987). For every family to occupy a separate dwelling by the year 2000, approximately 200 000 units per year will have to be built outside the "homelands" alone (SAIRR,1987:12). This is clearly an enormous task.

The conventional approach to design for commercial and high-income domestic buildings in South Africa has generally meant following current architectural fashion and leaving thermal problems to be solved with high-tech air conditioning. This is not an option for the low-income sector, and it is here where the greatest need for sensible energy efficient design lies. In a country like South Africa, where seasonal temperature variations are generally not extreme, it is possible to design energy efficient dwellings without adding appreciably to the final cost. Also, with this country's abundance of sunshine, it makes sense that this resource should be widely exploited in the design of new houses.

3.6.2. The Science Of Passive Solar Design

In any unconditioned building, the indoor environment is a function of the way in which the building modifies the prevailing outdoor environment. This is known as the thermal performance of the building. Energy efficient housing design uses principles and technologies developed specifically to optimise the thermal performance of a building, and so maximising the thermal comfort of the inhabitants. Thermal design technology can be roughly divided into passive and active systems. Active systems involve some form of added energy, like forced circulation, heat pumps or pneumatic controls. They tend to be expensive, involving automatic controls and sophisticated machinery, and would probably only be economic in situations where the unit cost of energy for space heating is extremely high and climate is severe. Passive systems regulate indoor climate only through the design of the building itself. They involve no machinery or additional energy input. Passive systems can be relatively cheap and unsophisticated, and require no special maintenance. However they can be less efficient than active systems.

One of the significant differences between passive and active solar design is cost. It is mainly the high cost of active solar systems that make then unsuitable as a serious answer to the energy problems of low-income urban households. Also, the South African climate is seldom severe enough to warrant expensive active systems.

Much of the international research work in active and passive solar design has been undertaken in relation to up-market housing and commercial buildings, and relatively little work has been done on low-cost mass housing. In most cases, the work has also been specific to the temperate climates of North America and Europe and would not be directly applicable to the Southern African environment. More recently however, there has been some research on the establishment and verification of computer-aided thermal design specific to South African conditions.

The design of dwellings to suit the climate can be seen as a complicated science on the one hand, or as a matter of "common sense" on the other. There are a number of simple considerations, if implemented at the design stage, that can do much to improve the thermal performance of a house for a fraction of the total construction cost. However, to design a house whose thermal performance will be optimised under various climatic conditions is an extremely complex calculation, one well suited to the use of computers.

A ready definition of a thermally well designed dwelling is one which maintains a steady, comfortable indoor temperature, while the outdoor temperature may vary through the day and through the seasons. This requires that the house should retain heat in cold weather or in winter, and loose heat in hot weather. Some factors influencing the thermal performance of a building, and simple measures that can be taken to maximise it are discussed below. In addition to being fairly simple and common sense, these design considerations would benefit the occupants without vastly increasing the overall construction cost.

<u>Shape and form</u>
Ideally the building should be compact with a low surface area-to- volume ratio, since it is through the surface that heat losses and gains occur. The ratio between window and brick area should be limited to about 20 to 25 percent of the total facade area to prevent excessive heat transfer through windows (Birrer,1988)

Sun exposure

The sun can be both a friend and an enemy. The obvious practice is to exclude the sun in summer and to admit it in winter. This is fairly easily achieved by correctly positioning windows and using roof overhangs. Overhangs not only prevent the summer sun from entering windows, but also shade the walls. Ideally the building should have a large surface, major windows and adequate overhangs on the north side. East and west facing walls and windows should be kept to a minimum surface area. In addition to direct solar radiation, there is also the effect of diffuse and reflected radiation from other sources, such as paved areas adjacent to the house. Attention should also be paid to the absorptive and emissive properties of surfaces..

Ventilation

The provision of cross ventilation in summer to remove heat is an important factor. Different ventilation paths into the house can be designed for summer and winter conditions, for example, directing cold winter air through a warm north-facing room, or warm summer air through a small shaded courtyard.

Mass

The mass of the dwelling acts as a heat store, absorbing heat when temperatures are high and releasing it when temperatures drop. In that way building mass dampens outdoor temperature fluctuations and keeps the indoor temperature around the daily mean. In low-cost housing, the walls and concrete floor would be the main mass components. Inland, where the temperature fluctuations are great, a high mass building is desirable, while on the coast it is unnecessary.

Insulation

Where a structure's surfaces are exposed to intense heat or cold (such as the roof), the heat flow can be controlled by surface insulation. Most insulating materials act by trapping air within a matrix of inert low-conductivity material and since it is this air which is the principal insulator, it is important that the insulator remain dry. In cases where the insulation forms a layer in a sandwich of construction material, the layer should be continuous and not bridged or broken at any point.

While not specifically "energy efficient", the planning of township or estate layout could include provision of sidewalk vegetation and recreational parks to help to provide a "feeling" of coolness in summer as well as being aesthetically pleasing, reducing dust and breaking wind flow.

3.6.3. Computer-aided Design Tools

The past few years has seen the rapid advancement of desk-top computer based programmes for evaluating and improving thermal performance of buildings. These are becoming increasingly accessible and have the potential of providing an easy and quick method for architects, designers and planners to incorporate energy saving features into mass low-cost housing. There is a range of programmes available from simple models requiring many assumptions, to more sophisticated models which may include detailed data files on standard building materials and climatic conditions for different sites. At the concept formation stage and at the final design evaluation stage, models can predict the thermal performance and maximum, minimum and average temperatures inside the proposed structure at various times of the year. The better computer programmes are highly interactive allowing rapid assessment of the thermal performance of various building materials or structural changes as the design proceeds, thus allowing the user to optimise thermal performance while keeping building costs within a budget.

There are a number of computer-based passive solar design tools on the market, the majority of which have been developed in northern hemisphere countries, and not all are applicable to conditions in South Africa. Local development in this field was spearheaded by the former National Building Research Institute (NBRI) of the CSIR. The first local design aid developed, a manual calculation procedure, was the Capacity Resistance (CR) Method (Wentzel et.al.,1981). An improvement was subsequently offered in the Electric Analogue Capacity Resistance (EACR) Method (Mathews,1985) and coded for micro-computer. An improved version of the CR-Method, incorporating some aspects of the EACR-Method, has also been coded for micro-computer, although with its primary purpose as an educational tool (Steenkamp,1988). The most advanced locally developed program was to be the Energy Design Technique (EDT), potentially comparable with the best offerings from Europe and America, but it's development has unfortunately been halted due to structural change within the CSIR, and there appears to be no immediate move towards resurrecting it. Research into passive solar design is presently being done through the architectural departments of the universities of Port Elizabeth and Pretoria. The two operational local design aids are reviewed below:

<u>The Capacitance-Resistance (CR) Method</u>
The CR-Method is an empirical model which predicts the minimum and maximum indoor temperatures for a building; given the materials of construction, general design details and layout. It makes use of extrapolation from a large base of experimental data and its general applicability has been demonstrated in field trials. The method is based on experimentally verified correlations between

- the ratio of the amplitude of daily outdoor temperature variation to that of indoor variation; and
- the total heat storage capacity of the building and the resistance to heat flow of the building shell.

Area and wall thickness data are taken directly from plans while thermal properties of different materials and climatic information can be gleaned from tables. The CR-Method was originally developed as a manual calculation procedure although an improved version coded in BASIC is available for use on micro-computers.

Limitations of the CR-Method (Mathews,1985 in Steenkamp,1988) are that the method:

- does not fully cover solar radiation effects, since it assumes that all windows are shaded and all external walls are of uniform colour;
- does not accurately predict the mean indoor temperatures;
- cannot predict the effect of different ventilation rates on indoor temperature;

- cannot predict time lags between indoor and outdoor temperatures;
- ignores heat generation from within the building; and
- does not easily predict the effect of some passive solar techniques such as Trombe walls.

The EACR-Method

Most of the CR-method limitations described above are overcome in the EACR-method. It is a semi-empirical method using electrical analogue theory as well as some techniques and data from the CR-method. The thermal driving-force used in the calculations is not the external air temperature, as in the CR-method, but the so-called sol-air temperature. This is a parameter which combines ambient air temperature with solar radiation.

A computer program for this method has already been developed and includes a full data base for the necessary thermal properties and climatic information. The computer package is easy to use but is limited in that it does not adequately handle the effects of direct solar gain in that it assumes all walls and windows are shaded. Future planned extensions to the programme will increase the scope of the method by providing information on ventilation, internally generated heat loads, and updating the data base to include materials commonly used in low-cost housing construction (Steenkamp,1988).

3.6.4. Field Experimentation

The usefulness of thermal design methods is limited by their accuracy at predicting reality and there is a dire need for the validation of the various models against measured thermal performance of different structures under different local environmental conditions. The first full-scale validation studies in South Africa were started in 1978 by the former NBRI. Known as the Low Energy Experimental House Project (LEEHP), it involved building two houses in a Pretoria suburb on adjacent stands and with similar floor plans. The control house was built according to a standard design, while the other included a variety of novel energy-conserving features including:

- double glazed of windows;
- large north-facing windows;
- wall and floor insulation; and
- additional thickness roof insulation.

Temperatures and heating loads inside both houses were monitored. Among the results obtained by comparing the two houses (Basson et.al.,1986) was that without roof insulation, the standard house was consistently colder in winter by between 4 and 6^{O}C. A cost-effective analysis showed that up to 80mm glass fibre ceiling could be justified in terms of saving of energy for space heating. This figure was reached presumably on the basis of electricity as the primary space heating energy source. There were a number of other results and conclusions in this study which, however, do not apply to the low-income housing situation.

Following the preliminary results of LEEHP, six houses of similar design were built in Mitchell's Plain, near Cape Town to test solar design principles in the winter rainfall area. This was known as the Cape Low Energy Experimental Housing Project (CLEEHP). Four of the six houses included various passive solar features while the remaining two reflected good building practices. Some information on the performance of Trombe walls and insulation materials was gathered but due to the corruption of years of computer-stored data, no meaningful results with respect to design model verification could be produced. The CSIR has halted all research into experimental solar design and, considering the cost and time involved, it is doubtful whether such work will be taken up in the near future. Without an extensive validation of the available models under local conditions, their accuracy and reliability in predicting thermal behavior of structures, and their suitability as design tools remain questionable.

3.6.5. The Potential for Passive Solar Design

Although South Africa is blessed with a temperate climate, in most parts of the country, seasonal extremes require a degree of heating or cooling in the home, demanding an energy input. Solar energy is a "free" resource and certain aspects of passive solar design can provide an effective way of harnessing this resource to benefit those who can least afford to spend money on heating fuels. In sections above, some aspects of the "common-sense" wisdom of passive solar design have been discussed. It has also been shown that passive solar design is well adapted for use on micro-computers, allowing a rapid and sophisticated optimisation of thermal comfort in buildings. A more comprehensive review of local and overseas computer-aided solar design packages can be found in a report by the Energy Research Institute (ERI) at the University of Cape Town (Back,1987). This report also highlights the difficulty of accurately modeling the very complex situation of heat flow through a building, particularly with regard to natural ventilation and cooling.

The thermal performance of the standard government-issue low-cost house found in most black townships (the NE 51/9 type), is notoriously poor. These houses have no ceiling, no roof overhang, and an arbitrary directional aspect, as noted by O'Donovan (1988), "...the result of an accountant attempting to do an architects job." Passive solar design principles can be introduced into a house design with a minimal increase in cost. However, as an appropriate energy technology for underdeveloped urban areas, the introduction of passive solar design principles into effective practice requires more than just a change in the window details or the floor plan of the NE 51/9, but needs to be coupled with a completely new response to the wider issue of providing low-cost housing for the urban poor.

As a first step towards improving the comfort conditions, planners and designers of new mass-built low-cost housing schemes must be made aware of the full range of needs (including those relating to thermal comfort) of the prospective residents, and of the implications of poor thermal design. The planning and construction of mass-built low-cost housing has seldom, if ever, included input from the prospective owners or tenants. Designers therefore have had little idea of what is important to the residents. Designers also have to be made aware of the relative ease with which the "common-sense" improvements could be made without a significant increase in construction costs. In short, to paraphrase Schumacher, design houses as if people mattered. However, the impact of well-designed mass housing is limited. While the state has in the past taken the major responsibility for the provision of low-cost mass housing, it is already shedding that responsibility. Formal housing options for the poor are being narrowed down to self-built houses on site-and-service schemes, or at most, the provision of "core" houses only.

Apart from new housing schemes, there is the possibility of retro-fitting some half a million existing houses to improve their thermal performance. In this regard, there is a need for research into cheap and easy methods that people could apply to improve the thermal performance of their own homes as well as programmes to disseminate the technology, since households willing to make improvements may not be aware of good design principles. Restrictions on home ownership in the townships, and the consequent lack of security of tenure, however is a major discouragement to tenants wishing to finance their own home improvements.

CHAPTER 4

TECHNOLOGIES FOR HOUSEHOLD ENERGY SUPPLY IN RURAL UNDERDEVELOPED AREAS

4.1 Introduction

The domestic energy situation in underdeveloped rural areas in South Africa, regarding consumption patterns and problem solving strategies has been outlined in some detail in the previous chapters. Possibly the most outstanding feature has been shown to be the almost exclusive dependence on wood as a primary domestic fuel. While there are some rural areas where a wood shortage is not evident, it has been shown that at present consumption rates, the total depletion of all "homeland" wood supplies within the next 40 years is almost inevitable. Unless urgent steps are taken, the ecological and social cost to these regions and their inhabitants will be enormous.

There are three possible ways of preventing the spectre of wide-scale deforestation in the "homeland" areas. The first involves tree planting programmes extensive enough to keep apace with demand, the second involves the introduction of methods using wood more efficiently and the third, the introduction of substitute fuels. In practice, no single method is likely to be enough and the preferred route would be a combination of all three with particular emphasis in particular areas.

In the medium to long term it is possible that more sophisticated energy sources will begin to supply an increasing proportion of the energy needs of rural households. In the mean time, dependence on wood is likely to remain the major feature of the energy situation in rural areas. This means that afforestation, and the development and introduction of efficient wood burning stoves, will be key elements in any rural energy programme. This chapter will look at:

- afforestation as a technology for sustaining a renewable crop of fuelwood;
- charcoal making and energy efficient stoves as technologies which use wood more efficiently;

- biogas, solar cookers, hotboxes, solar water heaters, solar design of houses and photovoltaics as renewable energy technologies which can lessen or totally replace the use of fuelwood; and
- grid electrification of rural areas as an inevitable but fairly long-term solution.

In each section, a background of the technology will be given along with the context in which it is envisaged to apply, followed by a fairly rough economic analysis where applicable and finally a discussion of some recent case-studies.

4.2. Afforestation

4.2.1. Introduction

Wood is the most widely used household fuel in rural areas in South Africa. However the dependence on wood is complicated by a shortage of natural afforested areas. Fuelwood collection itself is one of the causes of deforestation in rural areas. Other reasons are the demand for agricultural land, the harvesting of building material and the inevitable veld fires, all symptoms of increasing pressure on the land. Presuming that the regenerative capacity of natural woodlands and forests is limited by climatic and biological factors and that rural populations will increase, it is clear that at some point the rate of wood consumption will outstrip the natural regenerative supply. In many African countries this point has already been passed. It is estimated by the World Bank that the annual rate of tree consumption is exceeding supply through tree growth by 200% in Niger, 150% in Ethiopia, 70% in Sudan and by 30% in the Sahel countries (FTEE,1986).

Deforestation from whatever cause has a multi-pronged effect. The increased scarcity of wood means that more time must be spent collecting it, thus reducing time available for other more productive activities. Increasing scarcity is usually accompanied by increasing demand, rapidly and inevitably leading to destruction of the tree cover, environmental degradation and loss of land fertility. In severe cases rural people are forced to burn cow-dung, a major source of nutrient replenishment to the soil, thus accelerating the decline of soil fertility caused by loss of tree cover (White,1979:1). Afforestation programmes should thus be seen not merely as a means of providing wood for consumption but also as a means of restoring the ecological balance.

The extent of the "fuelwood crisis" in South Africa has been discussed in Chapter Two. In this section, the potential of afforestation programmes dedicated to the supply of fuelwood and building materials as one way to combat deforestation will be examined. This section will look at the areas required for plantations, the different approaches to tree growing and will review current activities in this field in South Africa.

4.2.2. Plantation Requirements - Current and Projected

Fuelwood demand in underdeveloped areas is currently supplied from indigenous forests, self-seeded exotics, village woodlots, residues from commercial plantations and white owned farms, and natural shrubland and woodland. Taking into account the supply from these sources and estimates on demand, a model developed by Aron et.al.(1989:27) shows that South Africa has faced a fuelwood deficit since the early 1980s. By far the major source of fuelwood is the naturally occurring shrubland and woodland in areas not utilised for agriculture, with the other sources contributing an almost negligible amount to the overall supply. The model predicts that if present fuelwood consumption trends continue, and no trees are planted, natural woodland will be almost entirely denuded by the year 2020.

For woodlots alone to replace the major fuelwood source is clearly an enormous task. The required plantation area for each "homeland" by the year 2000 as shown below:

Table 4.2.1. Fuelwood Deficits and Plantation Areas Required for Individual "Homelands" by the Year 2000

HOMELAND	FUELWOOD SUPPLY (1000 tonnes/year)	DEMAND	DEFICIT	PLANTATION AREA REQD. (ha)
Bophuthatswana	552	603	51	14 000
Ciskei	256	175	—	—
Gazankulu	643	375	—	—
KaNgwane	130	125	—	—
KwaNdebele	44	207	163	20 375
KwaZulu	475	2 511	2 036	203 600
Lebowa	794	1 436	642	80 250
QwaQwa	0	56	56	11 200
Transkei	875	2 311	1 436	179 500
Venda	475	505	30	3 750
TOTAL	4 235	8 304	4 414	512 675

Source: Aron et.al.(1989:29)

The planting of trees in South Africa for specific use as fuelwood or building poles is nothing new. The first recorded woodlot programme was in 1893, near King William's Town. Further woodlots were planted in the Ciskei area and further east in the Transkei around the turn of the century. Firewood shortage was also noted in Lesotho in a report in 1906, but woodlots were not planted on an organised scale in that country until the 1930s and then it was also done as a donga reclamation exercise (Gandar,1988). Despite a long history, the present area under woodlots in the South African "homelands" is far from what is required to meet demand.

The table below shows the distribution of woodlots in the "homelands" according to 1983 estimates. By comparison, the area under commercial plantation in South Africa excluding "homelands" was over 1.1 million hectares (Aron et.al.,1989:14).

Table 4.2.2. Areas of Woodlots for Fuel and Pole Production in the Homelands as Estimated in 1983

HOMELAND	AREA OF WOODLOT (ha)
Bophuthatswana	1 000
Ciskei	650
Gazankulu	143
KaNgwane	2 400
KwaNdebele	0
KwaZulu	9 167
Lebowa	1 000
QwaQwa	386
Transkei	12 000
Venda	466
TOTAL	27 212

Source: (Aron et.al.,1989:14)

Although increasingly attention has been drawn to the fuelwood issue, and to the establishment of woodlots as a strategy to counter deforestation, there has so far been little concrete action on the part of the authorities. The woodlot schemes listed in a later section while pleasing to note, contribute only a little way towards what is required to meet the demand. But even if afforestation programmes were to be actively instituted supported, it is possible that there would not be sufficient suitable land in the "homelands" for this purpose. A recent forestry guide plan for South Africa (Dept of Environmental Affairs,1982) has identified just under 750 thousand hectares of land within "homeland" areas which had potential for commercial exploitation. Areas in the individual "homelands" are classified as "good" or "marginal" and are shown in the table below.

Table 4.2.3. Suitable Land for Commercial Afforestation in South Africa and the "Homeland" Areas

HOMELAND	GOOD LAND (ha)	MARGINAL LAND (ha)	TOTAL (ha)
Ciskei	12 400	15 200	27 600
KaNgwane	75 000	—	75 000
KwaZulu	178 000	272 200	450 200
Lebowa	37 400	4 100	41 500
Transkei	100 000	—	100 000
Venda	29 300	18 500	47 800
TOTAL	432 100	310 000	742 100
S. Africa (excl. homelands)	964 500	524 600	1 489 100

Source: Aron et.al.(1989)

It is clear from the totals in the preceding three tables, that theoretically, the "homelands" have enough land suitable for tree growing. These totals are summarised in the table below.

Table 4.2.4. Afforestation in the Homelands: Requirements and Availability

HOMELAND	WOODLOTS IN 1983 (ha)	AREA REQD. BY 2000 (ha)	AREA AVAIL. IN 1982 (ha)
Ciskei	650	—	27 600
KaNgwane	2 400	—	75 000
KwaZulu	9 167	203 600	450 200
Lebowa	1 000	80 250	41 500
Transkei	12 000	179 500	100 000
Venda	466	3 750	47 800
TOTAL	25 683	467 100	742 100

In practice however, there are a number of reasons why the land suitable for woodlots would be considerably less, namely:

- large woodlot schemes would find themselves competing for land against more lucrative commercial forestry interests;
- availability of suitable land is not distributed evenly among all the "homelands";
- land use patterns may not favour woodlots; and
- village woodlots are feasible only on land within walking distance of villages.

In addition, the assumptions used in Table 4.2.1. to convert fuelwood demand to woodlot area required are based on biological growth data and take no account of the efficiency or style of woodlot management. As pointed out by Gandar (1988), most of the existing woodlots in the "homelands" produce at well below potential, and a large but unknown area remains completely unproductive. The reasons for this low productivity stem largely from poor management and include the facts that:

- only woodlots close to villages are fully utilised;
- in some woodlots, bad management has allowed trees to become too mature for use as fuel or poles, and too difficult to harvest with hand tools;
- the way in which the wood is sold or cutting permits granted may not correspond to actual demand; and
- where cheaper or free wood is available, the woodlots are underutilised.

Arenhold (1983) suggests that only a quarter of the land identified by the Forestry Guide Plan (Table 4.2.3.), or some 185 000 ha is in fact readily available for afforestation. It is clear that woodlots alone can satisfy only a portion of the demand projected by the Aron model.

4.2.3. Afforestation Technology

The shortage of fuelwood and tree cover in rural areas is seldom followed by a spontaneous tree-planting response. Because of this, afforestation requires organised programmes which encourage and motivate the planting of trees. In South Africa, afforestation experience has been almost exclusively limited to large commercial or state plantations dedicated to the paper and pulp, mining and wood processing industries. In other countries, large amounts of money and effort have been directed to afforestation specifically for fuel provision. China began a tree planting programme in the 1950s, and by 1978, some 28 million hectares of forest were reported to have been planted by the communes and collectives (Foley & Barnard,1984). In both India and China, there have been active programmes encouraging the planting of trees alongside roads. In the late 1970s, the Forestry Service of the Indian state of Gujarat was planting along roadways at the rate of some 1 500 km per year. The Republic of South Korea provides another example where acute wood scarcities and serious environmental consequences have prompted a nationwide tree growing programme with dramatic results. In 1962, the promotion of reforestation on a communal basis, was adopted as a major national priority. After substantial progress over the next decade, a ten year National Forest Plan was launched in 1973 with a series of ambitious targets, including the planting of 1 million hectares of trees. Intensive efforts were made to mobilise village level support and collaboration. By 1977, the basic targets of the Plan had been reached, five years ahead of schedule (Foley & Barnard,1984). In the heavily populated island of Java, some 30 - 40 thousand hectares of the South American leguminous bush Calliandra has been planted by villagers and small farmers with almost no support from the government (Kristoferson & Bokalders,1986). Closer to home, the most notable success has been the work of the Lesotho Woodlots Project, which since 1973 has seen to the planting of some 7 000 ha of pine and eucalyptus for fuel and poles.

In dealing with the problem of wood shortage, conventional forestry techniques such as large single-species plantations have some severe limitations:

- They require a high degree of capital investment and skilled labour input, both in their establishment and in their subsequent management. Capital and skills are often in short supply in underdeveloped rural areas.
- Large forests provide a central source of wood while the need for trees is dispersed. Wood may thus have to be transported, increasing its cost.
- The preference for certain species may differ from place to place, while plantations are usually restricted to one species only.

Farm and community forestry techniques offer a new approach to dealing with these problems. By assisting rural people to plant trees themselves, afforestation costs can be reduced and trees grown where they are needed in the quantities required and the species preferred. Households are thus allowed to choose their own priorities and act in response to their own needs. The importance of this new approach is reflected in the significant shift in attitudes to tree growing programmes and the funding of forestry projects. Since the 1970's, many national governments have been taking steps to reorientate their forestry policy towards greater emphasis on community involvement and the meeting of basic needs. Between 1975 and 1985, more than 130 farm and community forestry related programmes were initiated in over 50 countries, with a total funding commitment by international donor agencies in excess of US$ 750 million (Foley & Barnard,1984)

In farm and community forestry projects worldwide, four different basic approaches have been identified, based on extent of control and qwnership. These are namely, farm forestry, tree-growing for family use, community forestry and land allocation schemes. These categories are not rigidly defined or mutually exclusive and some projects may consist of a mix of approaches. The review below of each of the four different approaches to providing communities with wood is taken from the publication by Foley & Barnard (1984) unless otherwise indicated.

<u>Farm forestry</u>

This term applies to programmes encouraging commercial tree growing by individual farmers on their own land. Trees are regarded as a cash crop and various forms of assistance are provided, which may include technical help, loans and free or subsidised seedlings. Such programmes are simpler and cheaper to design and run than community based projects and have had much success where there is a strong market demand for wood.

Farm forestry projects do not automatically provide widespread social and environmental benefits. Farmers generally choose to grow the species that will give them the highest rate of return, which may be for the pole market, rather than for fuelwood. Farm forestry also tends to favour the richer farmers who are better able to devote land to tree growing and can more easily provide the necessary labour and fertiliser inputs. Trees are generally not planted in areas most in need of rehabilitation and conservation, but in those areas where they will grow fastest.

<u>Tree growing for family use</u>

These programmes are usually applied where commercial tree growing is limited by insufficient market demand, and thus have to rely on non-market incentives. Results have generally been less dramatic than farm forestry. An interesting lesson emerging from this experience is that fuelwood scarcity alone is rarely a sufficient incentive for people to grow trees, particularly in those areas where natural bush or trees are still available, albeit at increased distances and effort for collection.

Where these programmes have been successful, farmers have often cited reasons other than fuelwood scarcity as the prime motive for planting trees, including the production of poles, animal fodder, fruit, shade, natural fences, and windbreaks. Such programmes therefore depend heavily on the careful identification of local needs and preferences and the tree species most suited to meeting them. Their greatest potential almost certainly lies in promoting the cultivation of tree species which provide multiple benefits rather than simply firewood.

Community forestry

Community forestry programmes by definition use available public or communal lands for tree growing. The resultant wood crop, or the proceeds from it's sale, is then distributed for the benefit of the community. The extent to which community members participate in the programme can vary widely from cases where the community simply allocate land to an outside agency, to where the planting, protecting and harvesting of the crop is entirely the responsibility of the community. In most cases the presence of an active forestry service is essential to the success of the project. Forestry services provided can include identifying a suitable site and suitable species, providing seedlings and planting instructions, assisting with labour, fencing etc. and helping with the harvesting and marketing of the wood crop.

Where there is a lucrative market for wood, community programmes may operate on the same commercial incentives as farm forestry. Communities may provide a large part of the costs and labour required to establish and manage the forest, and may look forward to substantial cash benefits. However, as in farm forestry, there is a danger that such programmes may work to the detriment of the very poor unless careful measures are taken to prevent this. Where there are no market incentives to grow trees, the degree of intervention by the forestry service is usually increased to include a more complete subsidisation of planting and managing costs. In such cases, community involvement is usually limited to providing labour for payment, or on a food-for-work basis. Where there is little cash incentive, or where fuelwood is a low priority, the land allocated by the community for tree planting is usually unused or unusable land and may be all but inaccessible or far from the village.

Communal programmes, in principle, offer a number of advantages over individual tree growing. They allow the landless and poor households to share in the benefits of tree growing and can also provide a focus for community action against the gradual degradation of communal land through over-grazing and excessive wood consumption.

Community programmes nevertheless can run into severe problems, generally because they require a high degree of individual commitment to a common effort and for common benefit. Since the benefits of tree planting are only realised after a number of years, this commitment is often difficult to attain. In addition, a community's co-operation and the equitable distribution of benefits requires the existence, or establishment, of a democratic community organisation, which may not be the political norm in some areas. Community programmes require a great deal of careful design and painstaking preparation. They will rarely produce spectacular results but have the potential to promote broad-based socially and environmentally relevant rural development.

<u>Land allocation schemes</u>
In these schemes, land is allocated to families on condition that they grow trees on it. These schemes depend on a strong market for fuelwood and the availability of public or communal land which can be allocated. Benefits are that the poorest people in the community are not excluded, and previously uncultivated land can be made productive.

A variation of the land allocation scheme is the taungya system. Under this system, people are allowed to grow food crops between rows of young trees in exchange for working in the plantation. When the trees grow large enough to shade out the crops, the workers are allocated new sites. This system encourages good plantation management since workers have a stake in the success of the scheme. Such schemes could be particularly successful in areas of land scarcity and underemployment.

In addition to the four basic approaches outlined above, programmes can differ in respect of the tree species grown, and methods used to establish and maintain plantations. Despite an increase in forestry project funding, improved species development and an increasing shortage of wood, many tree-growing efforts have had a low level of success. One significant reason for this appears to be the problem of motivating rural families to translate their need for wood into tree-planting action. This apparent lack of motivation may be caused by a number of factors, but among them are the facts that plantations or woodlots may take up land that is more productively used for food crops or grazing, and that trees are seldom regarded as a "crop".

Agro-forestry, where tree growing is integrated with the existing agricultural system, is a technique developed to stimulate small-scale growing of trees as a viable crop. In this system, selection of species is all important. Fast growing tree species which coppice easily and have multiple uses are preferred, particularly those that would compliment existing farming practices. The trees are planted in and around cultivated patches or grazing pastures and the different parts of the tree (leaves, pods, branches) are used during the appropriate seasons for a variety of produce. The maximum use of land is attained while the trees provide fuelwood, building poles, windbreaks, shade and soil stabilisation. The young shoots, seedpods or fruit of certain species can serve as animal fodder while fallen leaves can provide a soil enriching mulch. Benefits of an agro-forestry system include more effective utilisation of sun, nutrients, and water; better soil protection; the economic benefits of increased total productivity; and the socio-economic advantages of leveling out seasonal fluctuations in labour demand, income, and expenditure and reducing the risk in farming. An agro-forestry programme is being initiated in the Ciskei by ARDRI at the University of Fort Hare. One tree species, the legume Leucaena leucocephala, holds great promise. It is fast growing, coppices well, provides shoots and seedpods for fodder and fixes nitrogen in the soil. Trial plots have so far been promising.

4.2.4. The South African Experience

While South Africa has developed a wealth of silvicultural knowledge and experience, it is almost completely limited to large commercial and state plantations. Afforestation projects or woodlot schemes in the "homelands", although designed to meet community needs, have largely been characterised by a lack of direct community participation, with the impetus for these schemes coming almost entirely from local government structures. Gandar (1988), offers a classification of woodlots in the South African "homelands" according to the form of organisational control over them, outline below.

- Government controlled woodlots are generally fairly large. Plantations of 100 to 300 ha are currently favoured by the forestry departments on the Transkei and Ciskei. These are wholly managed by department employees and wood is sold to recover expenses.
- Municipal woodlots were established many years ago around some towns in the Transkei and Ciskei to provide wood for their inhabitants. They were mostly successful but in recent years have been neglected.
- Tribal Authorities (TAs) in many areas have taken over control of existing woodlots or are encouraged to establish new ones. In KwaZulu, the forestry department provides seedlings and supervision, while the TAs are encouraged to input labour and some of the costs and to manage and maintain the woodlot. In the Transkei and Ciskei, the input from TAs in new woodlots is a lot smaller. Of the existing woodlots established in the 1950s and 60s by respective departments and handed over to TAs, these have almost without exception run into difficulties. These woodlots are often incorrectly referred to as "community woodlots".

- Community woodlots are those which are established out of the initiative of groups of community members. There are very few of these in existence in South Africa.
- Private woodlots are those which belong to individual households. They are generally small, ranging from 0.10 to 2 hectares. Such woodlots are not common except in certain areas such as Bizana in the Transkei.
- Non-Government Organisations (NGO's) although they have played a significant role in woodlot development in other countries, have not been very active in South Africa.

Some recent surveys of woodlot activity and initiatives towards farm and community forestry and agro-forestry in the "homelands" in South Africa are reviewed below.

Transkei

Plantations for firewood and building poles were established in the Transkei as early as 1893, with black wattle being one of the preferred species. In the 1960s, the Department of Forestry in the Transkei embarked on a woodlot programme, establishing 260 woodlots covering 14 000 ha. These woodlots were planted close to villages, but were established by government employees with little local involvement by villagers. Management was later handed over to the Tribal Authorities, but with little technical support from the forestry department. The consequence was poor management, ill-feeling amongst the villagers, insufficient yields, lack of firebreaks and damage by fires. The Department subsequently proposed to revert to large consolidated pole and firewood plantations of at least 100 ha each, established and managed by Department staff.

A woodlot scheme recently established in the Transkei, known as the Local Energy and Forestry (LEAF) Project, is a large Development Bank of South Africa (DBSA) funded project to establish 1 800 ha of village woodlots over a three year period. While the major portion of the DBSA loan will go to the Department of Forestry for the planting of trees, the funding bodies have at least recognised the limitations of previous woodlot management schemes and are sponsoring three concurrent projects (run by ACAT and TATU), to evaluate alternative approaches to community woodlots and investigate agro-forestry potential in the Transkei. The total amount of the DBSA loan is over R 5 million (DBSA,1985)

Kwazulu

By the end of 1984, some 40 small woodlots totalling about 150 ha had been established by the Forestry Department, and the plan for 1985/6 included the establishment of a further 62 woodlots totalling 216 ha. The accent has been on small village woodlots averaging about 4 ha. The Agricultural Division assists with fencing the site, the Tribal Authority supplies labour while the Forestry Division supplies the plants and supervises the operation. An extension forester is responsible for liaison and advice. Species which have been used include Eucalyptus grandis, E. paniculata, E. camaldulensis, E melliodora, E. oreades. Other species such as E. macarturii, E. nitens, E. maidenii, and E. sideroxylon are being planted on a smaller scale and some non-eucalyptus species such as Acacia mearnsii and Casuarina spp are also being used. (Anon,1985).

SAPPI's Project GROW

This project, funded partly by the Gencor Development Fund is aimed at encouraging afforestation in Kwazulu. Although fuelwood production is not the main objective, tree planting is encouraged through SAPPI's Mandini mill providing a ready market for logs. A grower wishing to join the scheme must sign an agreement to sell all the timber to SAPPI at the market rate applicable at the time of sale. SAPPI in return undertakes to provide advice, donate seedlings, and to pay a grower the cost of establishing his plantation. Potential growers are also paid an annual plantation maintenance fee and an interest free loan to be repaid upon the sale of the first timber crop. Wood for personal use is obtained from the branches and thinnings, although thought could be given to an arrangement whereby a portion of the individual woodlot is allocated for personal pole and fuelwood production.

The project began in 1983 and by February 1985, 67 growers had joined the scheme with a total of 104 ha under trees. The largest individual woodlot is 7 ha and the smallest 0,6 ha with the average being 1,4 ha. The project is reportedly growing fast and some impressive woodlots have been established within a short period of time. Tree growing is becoming a profitable venture because of the rapidly increasing timber prices and the demand for pulping timber. It was estimated that at 1985 prices, a grower could make a profit of R 2 500 per hectare over 10 years (SAPPI,1985)

Such a scheme could be replicated in other areas close to commercial paper or timber mills. Some potential problems areas are:

- the substantial input required to train and help individual growers compared to the small size of their woodlots;
- the large administrative burden placed on the timber company;
- the possibility of future transport cost escalations, jeopardising the more remote growers; and
- where wood is scarce, the growers may prefer to use all their wood, or may be able to obtain a better price by selling privately.

The scheme does have advantages in that it promotes the skills of tree planting and woodlot management, allows the cultivation of previously unproductive land, and has the potential to stabilise areas degraded through overgrazing and erosion.

<u>Ciskei</u>

Some initial surveys have been done by the University of Fort Hare to asses the extent, condition and distribution of woodlots in the Ciskei and the extent to which these are used for fuelwood and poles. This work commenced in February 1986.

So far, sixty-one woodlots have been identified on small-scale maps and a library of aerial photographs is being assembled. Of the identified woodlots, 32 have already been visited for a more detailed survey. Very little concrete results can be put forward at this stage, but while most of the woodlots are apparently well utilised, they do not make a significant contribution towards fuelwood supplies to local communities. The rural communities themselves do not perceive woodlots as a sufficient source of energy for household requirements (Bembridge & Tarlton,1986).

Ihlathilibuyile - "The Forest has Returned"
An interesting woodlot project which has demonstrated the potential of the community woodlot approach is that undertaken at Embongolwane with the assistance of the Institute of Natural Resources of the University of Natal in Pietermaritzburg (DBSA,1986).

Amandla Wedoda Project
The Valley Trust's agricultural section has been working in the Valley of a Thousand Hills area to help communities and local co-operatives to establish their own woodlots. The approach is to establish communal woodlots as an extension of the existing communal garden system. The Trust has so far initiated three communal woodlots (DBSA,1986).

Gazankulu
The Forestry branch of the Dept of Environmental Affairs with the assistance of the Rotary Club of Louis Trichard, The Dept of Agriculture and Forestry of Gazankulu and the Elim Hospital have embarked on a trial to assess the suitability of using Leucaena leucocephala for woodlots and agro-forestry. Planting at three controlled sites in different parts of Gazankulu was started in Sept 1984 and by June 1986, the seedlings had been successfully established. Following the initial success, it was decided to establish more trials in different parts of the region. Seedlings raised in these trials have also been planted in a trial in neighbouring Lebowa (Von dem Bussche,1985).

ARDRI Forest Farming Project
This project at the Agricultural and Rural Development Research Institute, University of Fort Hare, aims to investigate the possibilities and appropriate

methodologies whereby the principles of agro-forestry may be introduced into the Ciskei. The objectives are to increase unit production in all categories of land of trees and shrubs for fuel, browse, land conservation and food production.

A nursery was established at the inception of the project for the production of exotic species. In addition, three trial sites containing a variety of both indigenous and exotic cultivars were established in locations that represent the extremes of environmental conditions experienced over the Ciskei (Underwood,1985).

One species has already shown itself to have outstanding possibility is Leucaena leucocephala. Originating from South America, this arboreal cultivar is leguminous, fast growing, drought resistant, can be coppiced for fuel, provides animal browse, while the leaves provide fields with a nitrogenous mulch. Its disadvantages include the possibility of uncontrolled spread, certain properties which may cause a loss of hair if used to excess, and a root which must be carefully handled during transplanting. Empirical data from the Kidds Beach and Fort Brown trial sites indicate that the cultivar has a high tolerance to windy conditions and protracted periods of drought. Growth has been excellent with the second year providing even higher trees after coppicing. The next phase of the project will involve trials at a further 5 sites based on the range and variation of pedosystems within Ciskei. Plans have been initiated to produce some 130 000 Leucaena seedlings which will form the first batch to be integrated into existing programmes. Extension will be directed to three main sectors: high technology and managed systems, community self-help schemes and individual rural and peri-urban farmers. Both multi-cropping and polymodal systems are advocated. A trial plot has been proposed in the Amatola Basin which would be designed for integrated intercropping with Leucaena providing windbreaks and nutrient mulches for annual cultivars such as maize (Underwood,1988).

Lesotho Fuelwood and Poles Project (FPP)

Although not strictly a South African case, the Fuelwood and Poles Project (FPP) provides an interesting view of intensive state participation in village woodlot establishment. The project began in 1973 as the Lesotho Woodlots Project (LWP) and was formally incorporated into the Lesotho Forestry Department in 1987. The principal aim of the project has been to provide the population with wood for fuel and poles, but also to reduce the use of dung, crop waste and scrub as fuel, and to regenerate environmentally stressed and eroded areas. Total plantation area is currently about 7 000 ha with a further 3 000 ha earmarked for tree planting. Recent figures estimate that by the year 2010, some 200 000 ha under trees will be needed to satisfy fuelwood demand, requiring a planting rate of 7 500 ha per year. Present planting rate is only 850 ha per year.

The extension policy of the FPP (and the LWP before them) has been to stress the importance and advantages of woodlots and then to leave the request for their establishment to the chiefs and villagers themselves through their Development Councils. In no instances has a higher authority been asked to impose a land use policy on the local communities. Once a request has been made and the agreement signed, the area is declared a Forest Reserve under the Forest Act by His Majesty the King. This guarantees security of tenure and the continued management and regeneration of the forest reserves while allowing the villagers to retain ownership of the land. Most woodlots are established on communal land classified as "unsuitable for agriculture and grazing" although if requested by communities, other land would also be used.

Once an area has been declared a Forest Reserve it is cleared, prepared and planted by the Forestry Division. Usually, labour is supplied by local villagers and is paid on a food-for-work basis under the World Food Programme (at scales equivalent or better than the cost of casual labour). Villagers are also subsequently involved to varying extents in weeding, stumping, coppice reduction and harvesting of the trees, as well as road building and maintenance, and the fencing and safeguarding the woodlots. The more mature woodlots are often opened to cattle for controlled grazing, which is particularly beneficial to the villagers in springtime when lands are being ploughed.

Wood sales are held from mature woodlots by the local forestry officer when sufficient demand is shown. Prices are set so as to be roughly 20% less than wood sold by local vendors. Thirty kilogram headloads of branches are sold for around 50 lisente and stems at M17.50 per m^3. Twenty percent of the revenue from wood sales is returned to the communities for use under approved community development schemes while 80% goes to the Forest Fund for further afforestation. This situation is not ideal since many of the poorer villagers do not have the ready cash to purchase fuelwood stocks to tide them over till the next sale. Another problem is the often remote location of the woodlots.

At present there are roughly 380 Forest Reserves throughout the country, concentrated mainly in the Lowlands and Foothill zones. The encouraging rate at which communal land is allocated for woodlots derives not only from a need for fuelwood and poles but also from the expectation of employment and income resulting from the woodlot establishment and eventual wood sales.

Although the Project has been successful in its short-term goals of establishing as many woodlots as possible, the environmental effects and the material contribution of the scheme to rural communities is more difficult to quantify. After 10 years of operation, there was little hard evidence to suggest that the increased accessibility and volume of fuelwood had improved agricultural productivity. It was also evident that dung burning and scavenging for wood in woodlot serviced communities still continued, possibly because these sources could be collected free of payment (Powell & Wellings,1983). The 10 years of operation have also brought to light some interesting problems which could adversely affect the longer term conservation and development goals. The following points are identified by Powell & Wellings (1983) as being essential to the long term success of the project:

- Adequate training of individuals in the local community at all levels, for employment as foresters, managers and administrators is essential. Equally important is the inclusion of a broadly-based conservation education programme extending from informal discussion with villagers through to the establishment of village conservation committees and its inclusion in the school curricula.

- The land tenure system should be adjusted, if necessary, to allow more suitable sites for woodlots. Land allocation of woodlots is generally the responsibility of the village headman who may allocate unsuitable land or land far from the village.
- The woodlot schemes so far have remedied a specific problem, but because of the absence of a broad-based education and development programme, have not served as a catalyst for rural development. For woodlot projects to become self-sustaining in the long-term, they need to be located within an overall development strategy.
- The management structure of a woodlot project has to be designed such that it has the support of both the village community and the higher government of forestry department structures, and needs to enable the free flow of communication between all levels. The establishment of village woodlots is more than just forestry on a small scale.

Before the incorporation of the LWP into the Lesotho forestry department, a project proposal for further funding was drawn up to include programmes in social forestry and agroforestry but was not well supported by the major overseas donor. Despite this, there is a strong feeling in the forestry department that social forestry and agroforestry should be encouraged with more participation and control from the communities, particularly in view of the high administrative costs of a centralised bureaucracy (Law & Eberhard,1990).

Some general problems experienced in the project that could possibly be addressed by a management structure based more strongly in the village communities are:
- the underutilisation of some woodlots;
- illegal grazing inside the woodlot boundaries causing damage to young trees;
- damage to fences and theft of fencing material;

- illegal felling; and
- malicious damage to trees and arson, often due to disputes over land ownership.

4.2.5. Fuelwood Supply Strategies

Conventional forestry in South Africa has for decades served the interests of commerce and industry only. Any alternative approach, such as agro- and community or social forestry would thus demand new skills and a change in attitudes on the part of those involved in forestry. However, the opportunity for new and challenging possibilities is greatly increased, and given the existing base of technical and scientific silvicultural knowledge in this country, experience in South Africa could serve as a model for similar schemes elsewhere. Apart from the few case studies outlined above, the bulk of afforestation experience in southern Africa has come out of programmes in Botswana, Lesotho, Zimbabwe and Malawi, and much could, and should, be learned from these programmes. The local southern African experience and the large base of literature on afforestation provides a number of general points that need to be considered in any future large scale afforestation programme for rural South Africa.

- The degree of dependence on wood in the rural areas, the rate at which areas are already being denuded, and the urgent need for a solution, indicate that an effective fuelwood supply strategy for South Africa will have to be led by the state. Although the private sector and NGO's have a role to play in individual projects or areas, they do not have the resources or infrastructure to institute programmes on a national scale.

- A number of different fuelwood supply options are available. State or public woodlots (historically the common approach in South Africa), could be established in areas where the community does not want to assume this responsibility, and the large, "efficiently managed" woodlots would ensure rapid afforestation. At the same time community woodlots could be initiated in those areas where organised communities want to become more involved in, and exercise control over, their new woodlots. Perceptions on who should plant and control the use of "communally-owned" trees are not universal and the important thing is not to impose a system that does not have local community support.

- There are three sides to an organised tree planting programme (Gandar,1988). Firstly technical aspects like the choice of site and tree species, methods used for planting, maintenance and harvesting etc., secondly, organisational aspects, including the allocation of various responsibilities, controlling of access and cutting rights, land acquisition etc., and thirdly distributional aspects such as marketing, pricing and allocation of profits. These aspects are all interactive and for a successful woodlot programme must be compatible and if possible, fall under a single authority.

- Many rural households still obtain their fuelwood requirements from surrounding natural woodland without payment. Only in the areas of greatest fuelwood scarcity has wood become a commercialised commodity. It is in these areas that the first efforts should be made towards woodlot establishment. It is also in these areas that afforestation projects have the greatest chance of success, not only because of the demand for wood, but also because the commoditisation of wood allows individuals to make money out of tree growing.

- Project proposals and planning must take into account locally perceived needs and priorities, rather than externally imposed preconceptions. However strong the imperatives at a national level, people will only take part in tree growing if it is both feasible and attractive from their point of view.

- There is no doubt that rural South Africans appreciate the value of trees. Rural energy surveys have revealed that people are aware of the increasing scarcity of fuelwood, and fuelwood collection is often mentioned by rural women as a particularly arduous task. However, where communities are living in poverty, there may be a number of more important priorities such as water, housing and education. The success of an afforestation programme would depend, in part, on the previous satisfaction of these more pressing needs. In many cases, tree planting is not be seen by rural people as the best way to counter fuelwood scarcities. Where this is so, programmes would have a better chance of success if they were geared towards planting trees to provide, for example, fruit and animal fodder, with fuelwood being a subsidiary benefit rather than the prime motive.

- Afforestation programmes need to be integrated with other rural development initiatives, particularly where the benefits of woodlots are not visibly obvious. The allocation of land for a woodlot, for example, may mean the loss of land previously used for grazing livestock, but the establishment of a livestock improvement scheme at the same time might make the apparent loss of benefits more acceptable. Land tenure practices, the uncertainty over who owns and controls the use of trees on communal land, and general shortage of arable land may also serve to inhibit the spontaneous planting of trees in deforested areas. It should be obvious that households involved in a day-to-day struggle merely to survive, may regard the uncertain and non-immediate benefits of tree cultivation as a waste of time, energy and money.

- Voluntary and non-governmental organisations have potentially an important role to play in afforestation programmes. While they may not have the resources to organise on a large scale, they can provide a much needed bridge between local communities and the state authorities promoting tree growing programmes. This is particularly the case when it comes to ensuring that the interests of women, and the poor and landless are taken into account.

- Aspects of afforestation such as choice of tree species, position of woodlot and wood harvesting among others, should take into account the needs of the women of the household. As the main gatherers and users of wood, women are more aware of emerging scarcities and more receptive to afforestation programmes, and it is essential that they be involved from the start in community woodlot schemes. In many South African rural communities, where the majority of men are absent migrant workers, women have in any case become the de facto household decision makers. In addition to direct involvement as potential woodlot users, the training of women foresters can also greatly help dissemination efforts and help transform the role of foresters from "policemen" to that of educators and community organisers.

- While the social and economic constraints of farm and community forestry are important, it is vital that the technical aspects of rural tree planting programmes suit the users. The further tree planting activities diverge from local experience, the greater the risks and it is important that supporting work be undertaken on species and management trials.

- Afforestation programmes require a secure basis of trust between programme promoters and local communities. Extension workers play a key role in establishing that trust. Training suitable extension staff and building up an effective and sustainable back-up system is often a long and costly exercise. It is essential that this is allowed for in both the budget and time scale of the programmes.

- The choice of species to be planted is important. A planting programme may fail because of a poor match of site and species. Failures at this early stage of the programme may destroy the credibility of woodlots in the eyes of the local community. Choice of species should primarily follow site characteristics and local preference. If the two are irreconcilable, choice should be in favour of the former, since people are more adaptable than trees.

- Most silvicultural research in South Africa is directed towards the needs of industry. There is a need for coordinated research into appropriate species, wood calorific values and comparative systems of woodlot management specific to

South African conditions. A basis for work in this field would be the experience gained in other southern African countries.

- Woodlot management often falls short in the final marketing and distribution of fuelwood. Wood has traditionally been a "free" resource, and when people buy wood, they are not paying for the wood as such, but for the convenience of not having to spent the time and effort collecting it. The convenience of the users should be the first consideration. Many existing woodlots are under-utilised because the bureaucratic procedure involved is more time consuming than collecting wood in the veld.

The need for trees is widely dispersed, extremely varied, and specific to the people involved. Approaches which allow a large degree of choice are thus more likely to yield results. "Appropriate" afforestation programmes should assist rural people to plant trees themselves, but allow families and communities to decide their own priorities, and grow the types and numbers of trees they choose in the locations they feel are more relevant to their needs.

4.3. Charcoal

4.3.1. Introduction

The shortage of fuelwood is not evident throughout the country. In some areas there is enough wood to cover present and immediate future needs, while in others, wood has to be trucked in from outlying regions and is sold as a commodity. However wood is not an economical fuel to transport over long distances because of its high bulk and low energy density. One alternative would be to convert wood into charcoal, increasing the energy density and therefore reducing the transport fraction of the final price. In addition to its higher energy-to-mass ratio, processed charcoal can be compacted and bagged, taking up less physical space than an equivalent mass of wood. The production of charcoal, while still adding to the overall depletion of wood resources, potentially allows a more managed situation of resource exploitation, and the cheaper transport costs of charcoal over wood allow a geographically larger area to be economically served. Benefits for the user are that charcoal is a smokeless fuel, it burns efficiently and is suitable for use in a small stove.

An estimated 370 000 tonnes of dry timber was used for charcoal manufacture in 1982 (Bennie,1982). Most of this wood was converted in relatively sophisticated processes. This is evident in the yields obtained of between 16% and 20%, and the estimated average production costs of between R60 and R90 per tonne of charcoal with 24% of this cost to labour, and 35% to capital equipment (Huy,1984). The estimated charcoal production in 1981/2 was 104 000 tonnes per annum from at least 42 producers. Of this, 36% is consumed by industry, 33% sold as a barbeque fuel, and 31% exported (Bennie,1982).

There is no tradition of small-scale charcoal production nor of its use as a domestic fuel in South Africa, although it is widely used throughout Asia and in Africa north of the Zambezi. Most production of domestic charcoal in these countries is produced using small-scale traditional methods. Reasons for the lack of such a tradition in southern Africa are not clear but are probably partly historic and partly a reflection of resource availability. This lack of local tradition could be a major obstacle to its wide-scale adoption in South Africa.

While charcoal may be more ecomonical to transport than wood, charcoal production can be extremely wasteful since a substantial portion of the energy in the wood is lost on conversion. Depending on the technology used, between 10 and 4 tonnes of wood, with an energy content of about 17 MJ/kg, are required to produce one tonne of charcoal, with an energy content of about 30 MJ/kg. The energy lost in conversion is thus anywhere between 60% and 80% of the energy content of the original wood.

4.3.2. Sources for Charcoal Production

Possible sources for charcoal production are numerous. There is a significant quantity of waste wood generated by the commercial forestry and saw-mill industry, and the clearing of alien invading vegetation from farmlands or nature reserves. The waste wood is usually dumped or burned because of prohibitive transport costs. There are also woodlots and wattle stands inside the "homelands" where the trees are too mature for easy harvesting on a casual basis, and would better suit a small-scale commercial undertaking. Finally it is possible that woodlots both inside or outside the "homelands" be established specifically for the production of charcoal.

The residues of commercial forestry and milling in South Africa are substantial. After-harvest residue left in plantations consists mostly of tree tops and branches, but because the waste is usually left where it falls, it would be necessary to change tree harvesting practices to facilitate charcoal manufacture from this source. The amount wasted in harvesting is over 1.8 million m^3 per annum (Sorfa,1983). The primary wood processing industry (sawmilling, paper & pulp, mining timber etc.) also produces considerable waste. While much of this is used by the industry as boiler fuel, some 1.4 million m^3 remains (Sorfa,1983). The total wood waste form these two sources is thus over 3 million m^3 per year. Not all of it is suitable for immediate charcoal production. Sawdust for example would first have to be briquetted. The secondary wood processing industry (furniture, veneer etc.) produces an estimated 301 000 m^3 of wood waste (Hose,1986). In this case the industry is geographically widespread which would not suit production economics.

Hose (1986) also estimates that more than 5 million hectares in South Africa carry sufficient invader bush for it to be harvested at a rate of over 4 m^3/ha/year, which means about 20 million m^3 of wood per year. There are already some small firms in the Western Cape producing charcoal from Acacia cyclops (Rooikrantz) and Acacia saligna (Port Jackson Wattle), both fast growing alien species, which are cleared on contract from nature reserves and farming land, and potential exists in many other areas of the country where encroachment bush has become a problem.

A more substantial source of wood for charcoal production would be commercial or state plantations, but these generally lie outside the "homelands". Plantations already provide wood to the existing charcoal industry which in 1982 consumed nearly 2% of the total roundwood input to the forest products industry, producing about 100 000 tonnes (Huy,1984). More than half of this was produced from wattle, about 40% from Eucalyptus, and a small amount from other hard woods and softwoods. Most of the charcoal from this source is produced in the Natal Midlands (within reach of KwaZulu), and a about third in the south-eastern Transvaal.

The table below summarises the supply situation.

Table 4.3.1. Potential Sources for Charcoal Production

SOURCE	QUANTITY (million m^2/yr)
Forestry Waste	1.8
Primary Processing Waste	1.4
Secondary Processing Waste	0.3
Alien Invaders	20.0

As will be shown below, charcoal production only makes economic sense if the end user is some distance from the source of wood, which effectively eliminates many forest resources close to heavily populated underdeveloped areas. An exception perhaps could be mature stands of eucalyptus or wattle which, when left to grow to large sizes are not easily harvested by local populations using hand implements, and are not suitable for burning in stoves or open fires. This situation has developed in a number of badly managed woodlots. A better solution in such cases may be small-scale co-operative commercial charcoal production which would allow the use of chainsaws to reduce the logs to a manageable size for charcoal production.

Finally, it is possible that plantations dedicated to the production of charcoal for underdeveloped areas be established. The industrial and export market for charcoal is likely to remain lucrative, and such a venture could help to finance the establishment of plantations and provide income for rural charcoal makers.

4.3.3. Charcoal Production Technologies

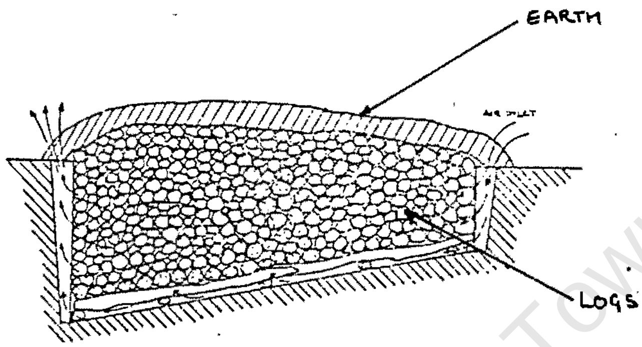
Charcoal is produced when wood is heated in a kiln without sufficient oxygen to cause full combustion. The process takes place in four main stages as the temperature of the kiln increases. The first stage up to about 200°C drives off all the water in the wood, while the second stage (200° to 300°C) drives off light volatile matter consisting of methanol, acetic acid and small amounts of carbon dioxide and carbon monoxide. The third and exothermic stage occurs when the bulk of the tars in the wood are released and finally, at temperatures around 500°C, all the volatile matter has been released. After this, the charcoal is allowed to cool and stabilise before being bagged.

The quality of charcoal is dependent on its final carbon content, which is dependent on the temperatures reached in the kiln. If high temperatures are not reached, the charcoal retains large amounts of volatile matter, has a lower energy density and tends to smoke when burned. Charcoal made at high temperatures is clean burning but may be difficult to ignite. The ideal compromise would have a carbon content of around 75%, a bulk density of around 250-300 kg/m^3 and a calorific value of about 30 MJ/kg (Kristoferson & Bokalders,1986).

There is a range of different charcoal making technologies from the very simple, cheap though relatively inefficient, to the capital intensive, high quality, automated kilns. The level of technology used is to an extent dependent on where the end product is marketed. Industrial and export markets require large quantities of consistent high quality product and is best served by centralised capital intensive production. In developing countries with a tradition of domestic charcoal use, technologies are generally smaller, cheaper and labour intensive with strong links with the local demand. A number of the smaller, labour-intensive production methods will be outlined below. More sophisticated, expensive kilns that can be bought "off the shelf", and that allow high production rates and optimum yields will not be discussed.

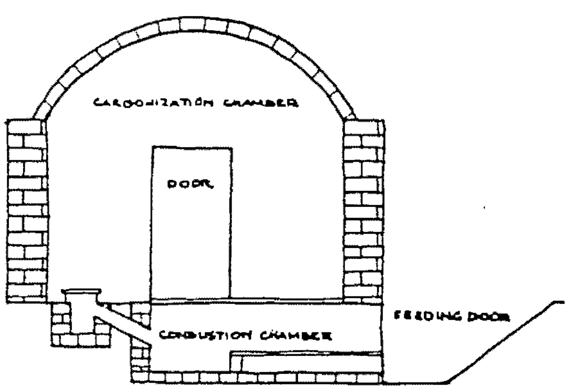
Possibly the most simple kiln is the rather crude "earth-mound" type where the wood is stacked in a pile, covered with green vegetation and finally the whole pile sealed with damp earth or clay. A variation of this is the "pit kiln" which consists of a trench dug in the earth in which the logs are placed. The pit is sealed with a covering of green leaves and branches and finally mud. Sizes of this type of kiln vary between 1 and 30 cubic metres. Conversion efficiency in this type of kiln is very low and, once fired up, the process is almost impossible to control. It requires almost no initial capital outlay or maintenance but is fairly labour intensive. Yields are about 20-25%.

Figure 4.3.1. The Pit Kiln



The other traditional type is the brick or concrete kiln. These are permanent installations and require some skill to build. Their permanence also means that they must be near to a reliable source of wood. They are easy to operate and produce better yields (25-30%) than the earth mount type.

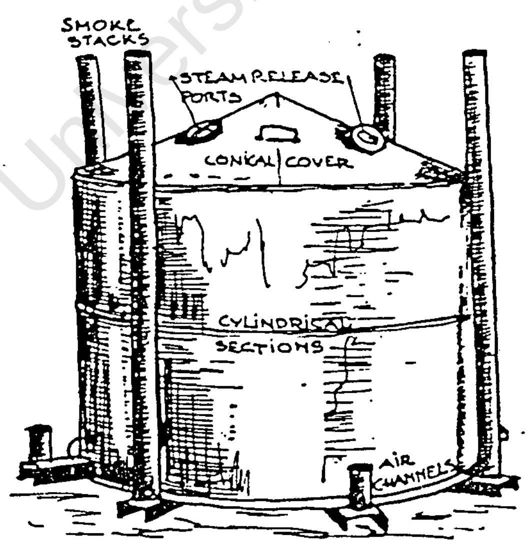
Figure 4.3.2. The Brick Kiln



There are a number of more efficient, transportable kilns which have been developed in recent years in Third World countries. The traditional charcoal-making methods outlined above, are highly wasteful and the development of new kilns has been largely focussed on reducing the consumption of scarce wood resources. Portability, another feature, allows the exploitation of a dispersed wood source, or on-the-spot production at a bush clearing front. Three of these "improved" kilns will be discussed below.

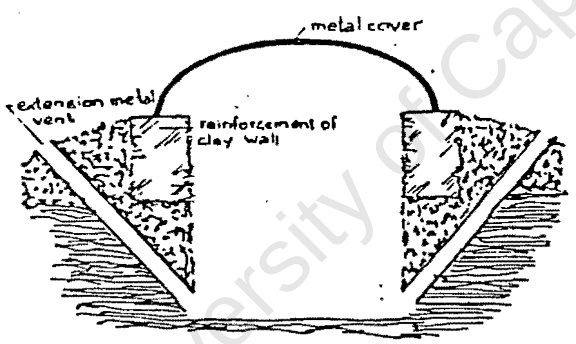
The Mark V kiln was developed by the FAO in Uganda and Kenya, but has also enjoyed some popularity in other African countries including Swaziland, which has recently installed a number of these for charcoal production from mature wattle stands and also from saw-mill wastes. They are easily built in small metal workshops and the simple operation lends itself to easy dissemination. With a diameter of 2,3 m and a $7m^3$ capacity, the kiln is extremely portable and, depending on the density and moisture content of the wood used, conversion efficiencies of between 20% and 30% can be achieved.

Figure 4.3.3. The Mark V Kiln



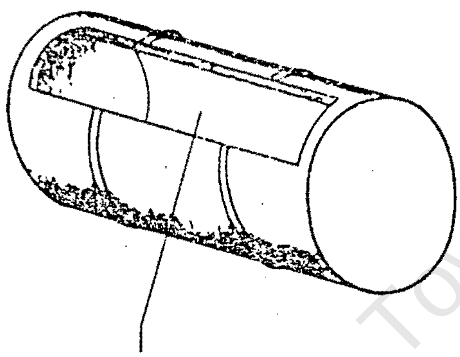
An even cheaper kiln, costing about a third of the Mark V type, is the Improved Pit Kiln developed by the Intermediate Technology Development Group in Liberia. The kiln has a capacity of around 8 m^3 of stacked wood, the majority of which is contained in a pit dug in the ground to a depth of about 1,8 m. The top of the pit is surrounded by a collapsible angle-iron frame onto which stock-sized mild steel sheets are secured. Joints in the cover are sealed with mud and a number of vent pipes (for air inlet and smoke outlet) are attached to the structure. Dry mass conversion efficiencies of between 25 and 30 percent have been claimed. The combination of increased conversion efficiency, simplicity of construction and operation, and relatively low capital investment makes this type of kiln an attractive proposition for developing areas.

Figure 4.3.4. The "Improved" Pit Kiln



The Energy Research Institute at the University of Cape Town has experimented with charcoal production using a Tongan kiln which is very simple and extremely portable. This consists of a commonly available 210 litre steel drum which has a "window" cut out of the side. The drum is lain on its side and the wood is fed through the opening. When the process is complete, the drum is rolled over until the opening faces downwards and earth is packed around the drum to seal of any air supply.

Figure 4.3.5. The Tongan Kiln



This kiln is presently being used in conjunction with an alien bush clearing operation in the Western Cape. In such an operation, portability is a major advantage in that the charcoal making can be done "on the spot" as the bush-clearing front progresses.

4.3.4. Economics of Production and Distribution

The economic advantage of charcoal over wood lies in the fact that it has a higher energy to mass ratio. Transported charcoal should theoretically be cheaper per unit energy than transported wood. However there are cost incurred in the production of charcoal which have to be accounted for. These costs broken down, comprise of the raw materials cost, labour, other running costs and redemption of capital equipment. Each type of process will reflect a different set of costs per unit mass produced. The table below indicates the relative costs for the production of charcoal from a number of different types of kilns and for different raw materials costs. The capital cost per unit gives an idea of the technological sophistication of the kiln.

Table 4.3.2. Charcoal Production Costs

KILN TYPE	CAPITAL COST (R/Unit)	PROD. RATE (kg/day)	PRODUCTION COST (R/ton) (for different raw matl.cost) (R0)*	(R18)*	(R37)*
Tongan	18	15	61	181	368
Mark V	3100	200	65	155	295
Cusab	3100	450	47	—	—
Armco	10 000	2 200	39	129	268
Gaylard	41 000	2 200	36	97	190

* raw material cost in R/ton

<u>Source:</u> Shaw (1989)

From the table it is evident that production costs are lower with sophisticated, high-rate kilns; and that the cost of the raw material makes a considerable difference to the final cost of the charcoal product. The case of zero raw material cost is based on using by-products from the timber industry; the R 18/ton approximates commercial harvesting of thicket or plantation timber; the R 37/ton is based on the 1988 price of firewood manually cut from alien brush thickets by rural contract labour.

In order to compete with wood, the costs of charcoal production have to be offset by the saving in transportation and assuming a fixed transport cost per unit mass of wood or charcoal, an economic "break-even" distance for each process and raw-material can be calculated. These distances are indicated in the table below. For example, with a Mark V kiln using raw-material at a cost of R18/ton, transport distances would have to exceed 650 km before charcoal becomes cheaper than wood on a cost per unit available energy basis.

Table 4.3.3. Break Even Distances for Charcoal Production

KILN TYPE	BREAK–EVEN DISTANCE (Km) (for diff. raw matl. costs) (R0)*	(R18)*	(R37)*	LANDED COST** (R/Ton)
Tongan	300	600	1 450	121
Mark V	350	650	1 100	135
Cusab	200	–	–	87
Armco	200	500	950	79
Gaylard	200	350	550	76
COAL	–	–	–	61

* – raw material costs in R/ton
** – based on a raw material cost of R 0/ton and transport cost of R 0.2/ton.km

Source: Shaw (1989)

It is interesting to note that the less expensive kilns produce a more expensive charcoal and therefore have a greater "break-even" distance. This is not compatible with the conventional view of appropriate technology where the production and marketing strategy would favour low-capital cost production and local de-centralised markets.

There are however some criticisms of the above analysis. Firstly, a raw material cost of R37 per ton for manual harvesting may not be accurate for all regions of the country and may be considerably lower in some areas. Similarly, the wood price with which charcoal would have to compete can vary from place to place. Secondly, Baldwin (1987) asserts that transport costs are primarily a function of vehicle depreciation and maintenance and are not directly related to distance transported. He also argues that in developing areas the limiting factor on transport is volume rather than weight.

Most important to the success of any charcoal production programme for domestic fuel use would depend on the users perception of its "value-for-money" as a fuel, compared to other available commercial fuels. This leads to the question of a standard charcoal quality. For local industrial or export markets, price per unit energy is obviously an important factor and the market price is directly related to quality. However, it is unrealistic to assume that rural households would be able to test the energy density of a particular batch of charcoal before paying for it, or that vendors would sell it on an energy content basis. It is more likely that sales and market price would be based on mass or volume. In this case, rural charcoal makers with a free and plentiful supply of wood would have little incentive to adopt a more efficient technology if it costs any more than the simple hole-in-the-ground. This lack of incentive to improve yields, accounts for the failure of many of the new "improved" kilns introduced in some African countries in an attempt to stop deforestation (Foley,1988).

4.3.5. Conclusion

As outlined in the introduction, charcoal is not a "wood saving" technology as such. Because of its higher energy density, theoretically it should be more economical to transport than wood, thus allowing for a managed fuel distribution network aimed at those areas where wood is no longer available. In reality it would seem that the "transport saving" is so marginal as to only operate over fairly large distances. There is also the argument that vehicle running costs are not strongly a function of mass of load and distance traveled, and that the saving is thus even less. Economic analysis seems to indicate that with present prices of wood and charcoal and production costs, charcoal is not an obvious replacement for wood as a primary domestic fuel.

A further problem is the lack of a charcoal making or using tradition in South Africa. A "charcoal programme" would experience the problems common to the dissemination of all new technologies, but be made even more difficult firstly, because cooking food is a highly culture-bound activity and cooking habits are difficult to change, and secondly, a market for charcoal and charcoal stoves does not exist, and would first have to be "created" in some way.

There is however, a lucrative local industrial and export market for charcoal. Charcoal-making operations on small plantations could provide employment and income in rural areas. The harvest in these plantations could, for example, be split between fuelwood, sold at nominal charge for local needs, and charcoal sold on the open market. The profits generated by charcoal making could be used to sustain the whole plantation and subsidise the price of fuelwood.

4.4. Fuel Efficient Stoves

4.4.1. Introduction

The problems experienced by households dependent on wood as their major fuel source could be lessened to some extent by more energy-efficient methods of burning wood. Traditionally, food is cooked or water heated in pots on a "three-stone" open fire outdoors, or indoors during bad weather or cold. With the open fire, most of the heat generated is lost to the surroundings, and the useful heat obtained from and open fire is only about 10% of the potential heat content of the wood. This can be increased to around 20-30 percent with a well designed stove which means that, compared to an open fire, only one-half to one-third the amount of wood is required to perform a similar cooking task.

The motivation for encouraging the use of fuel efficient stoves in rural areas has a number of broad aspects. Firstly, it is assumed that the use of fuel efficient stoves would lead to a reduced consumption of fuelwood which would have a positive impact on the rate of deforestation. Secondly, households using fuel efficient stoves would have the opportunity to save cash where fuelwood is sold as a commodity; or, time and effort where fuelwood has to be collected. Thirdly, the use of stoves would help to increase living standards and thereby speed up the transition from total dependence on wood to the use of other fuels and possibly electricity.

However, while many fuel efficient stoves have been shown to give improved yields in the laboratory and in the field, there is no conclusive evidence that households using stoves consume less fuelwood. In fact they may use even more. The use of a stove allows easier cooking and water heating and thus may be used more frequently and for tasks not possible on an open fire. There is also not always a strong link between the use of wood for cooking, and deforestation. There are many other pressures on the forests, most notably, the need for more land to hold an increasing population. There is also little connection between the availability of wood and the desire to own a stove simply because it uses fuel more efficiently. Most rural households in wood-scarce areas would welcome fuel savings, but this is seldom the primary motive for investing in a stove.

On the other hand, a stove does contribute to an improved standard of living, and is generally accepted to be an improvement on an open fire since it is safer, allows the kitchen to be kept cleaner, allows cooking with more than one pot at a time and the ability to cook while standing upright. A stove can be built to include an oven for baking and an attachment for "instant" hot water. Smoke from the fire can be led away from the cooking area in a chimney and some well designed smaller stoves can be made to be almost smokeless. The carbon monoxide, tars and soots in wood smoke are poisonous or irritating, and in a poorly ventilated kitchen, can reach levels where they pose a considerable health risk, contributing to eye and respiratory diseases.

Despite all the apparent advantages of stoves, the open fire remains popular. It costs nothing, requires no special tools or skills to construct, and can be placed in a convenient spot and moved with ease. Control of the cooking process is also very simple and effective. Heat transfer can be controlled by adding or removing logs of wood or by raising or lowering the pot. An open fire can also be made any size and can burn any shape or size of wood, as well as other fuels such as dung, grass and crop waste. Smoke also has its advantages. It has be shown to be an effective means of keeping certain thatch-eating insects at bay (Harrison,1980). The family fire in some cultures also serves as an important focal point for social interaction as well as a source of light. Nevertheless, as families earn more money, most are prepared to abandon the open fire in favour of a new stove.

4.4.2. Some Factors in Stove Design

There is a large body of literature describing the attempts of various international aid organisations, government bodies and individuals to design and introduce improved wood burning stoves into underdeveloped areas. Areas suffering from acute deforestation, the Indian sub-continent, the Sahel region and parts of Latin America have all been the subjects of such programmes involving almost every aid organisation (Dickson & Baldwin,1990). The vast range of stove experience exists partly because cooking is so culture-specific, and a successful stove programme depends as much on meeting specific social needs as it does on sound engineering principles. Before reviewing some of the more successful designs resulting from various programmes, it is instructive to consider the major considerations in designing a fuel efficient stove for underdeveloped areas. These are comprehensively listed in Dickson & Baldwin (1990) and can be broadly classed in three sections.

The first set of design considerations are the social aspects, which are to a large degree determined by the expressed needs of the target population, by their cultural cooking practices, and by the local levels of resources and skills.

- It is necessary to determine the types of food cooked, the accepted methods of cooking, the types and sizes of pot generally used and whether more than one pot of food needs to be cooked simultaneously.
- Safety and health requirements also need to be determined. Indoor stoves may present the possibility of burns to children and toddlers and the smoke may be irritating and unhealthy.
- The need for improvement in the comfort levels in the home and kitchen must also be assessed, and it is obvious that the stove should be appropriate to the physical kitchen environment. This will influence design parameters such as overall stove dimensions, hob height, portability and whether extras such as an oven or a hot water cylinder are required. The stove may also be required to perform a space-heating function.
- If the stove programme is to incorporate local manufacture it is necessary to assess the local level of skills and available materials. The availability of these will influence the choice of materials and method of construction. It will also influence the way in which the stove design is disseminated, since a home-made design will need more education/training support, while a workshop-made design will require marketing structures. The type of fuel commonly available is also an important design consideration.

- Such a survey should be aware that often the function of the family fire is not only to provide heat for cooking and space heating. An open outdoor fire may be preferred for reasons of habit, culture, taste and type of food cooked, that are not easily gauged by an "outsider". The white, male South Africans love of the Sunday Braai is a case in point.

Secondly, there are the technical aspects of stove design which will ensure a well engineered product. These include maximising heat fluxes to the pots, maximising the power output range over which the stove operates efficiently and choosing suitable durable materials, including features to make the stove desirable. The design process includes investigation into the combustion properties of the fuel and the relationship between the stove dimensions and the stove performance. Modeling of stove performance is extremely difficult because of the complex and unsteady-state nature of fuel burning rates, heat losses, and the heat transfer between the flue gasses and the cooking pot. Fuel consumption is as much a function of the operation of the stove as it is of the design. There are some theoretical models which the designer may use as a starting point but a final optimum design can only be achieved after extensive laboratory and field trials. Among other things, good fuel efficiency requires that the space provided for the pots be fully utilised while the stove is burning, and that fuel feeding rates correspond to the amount of heat required for the cooking task.

Finally, the materials used and the envisaged manufacturing method have to be chosen. The problem is to develop, from cheap and readily available materials, a stove which is also robust and attractive. Most low-cost woodstoves have had a poor record of durability, whereas the more expensive ones are unavailable to a large section of the poor rural community. The challenge is to try to meet the demands of durability and aesthetics while using cheap, familiar materials, producing a stove that can be made, repaired and maintained in small workshops or in homes. One of the difficulties facing a new entrant on the wood stove market in South Africa, is the competition from the wide range of commercially manufactured wood/coal burning stoves available. Although expensive, these can generally be bought on hire-purchase, and are available to rural people through well established existing retail networks. These stoves are long lasting and attractively built but are seldom very efficient. Designers of fuel efficient stoves have to be aware of perceptions of "what a stove should look like" and should avoid stoves that perform well but may be considered inferior because of their appearance or the way in which they are marketed.

4.4.3. Existing Stove Designs

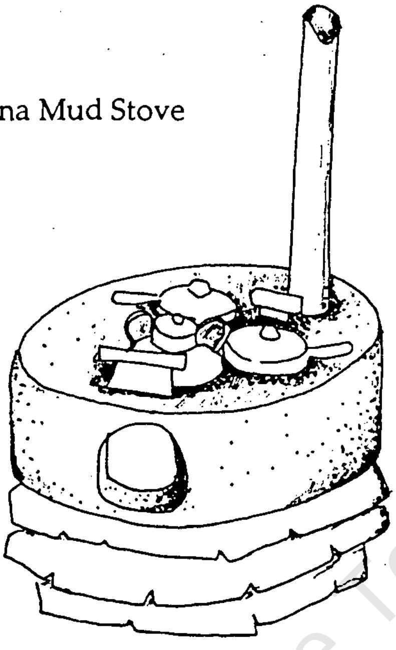
There are almost as many designs as there are stove programmes, and the range of different stove designs, both traditional and "improved" is wide. However, designs can be characterised roughly according to their main material of construction. The four categories are listed below (Dickson and Baldwin,1990).

High-mass Mud/Sand/Clay Stoves

These are usually very low-cost, owner-built stoves, and are made from whatever earthen material is readily available. The design of the shape, number of pot holes and overall dimensions may be determined by the user's requirements. This group includes any stove made from mud/sand mix, stones bonded with mud, fired bricks or concrete. These stoves have the advantage in that they can generally be built and maintained by their owners after a minimum of training.

Perhaps the most popular stove of this type is the Lorena, a result of one of the first major attempts at improving stove efficiency, introduced in Guatemala after a devastating earthquake in 1976. The Lorena is, with the exception of the damper and flue pipe, built entirely of a sand and clay mixture. After some trial and error to find the optimum clay-sand mix and some prior training and guidance, these stoves can be built by their prospective owners to their own requirements. The Lorena stove has been one of the most widely internationally disseminated stove designs although it has not always met with equal success due to the unavailability of the correct clay or the difficulty of training stove builders.

Figure 4.4.1. The Lorena Mud Stove

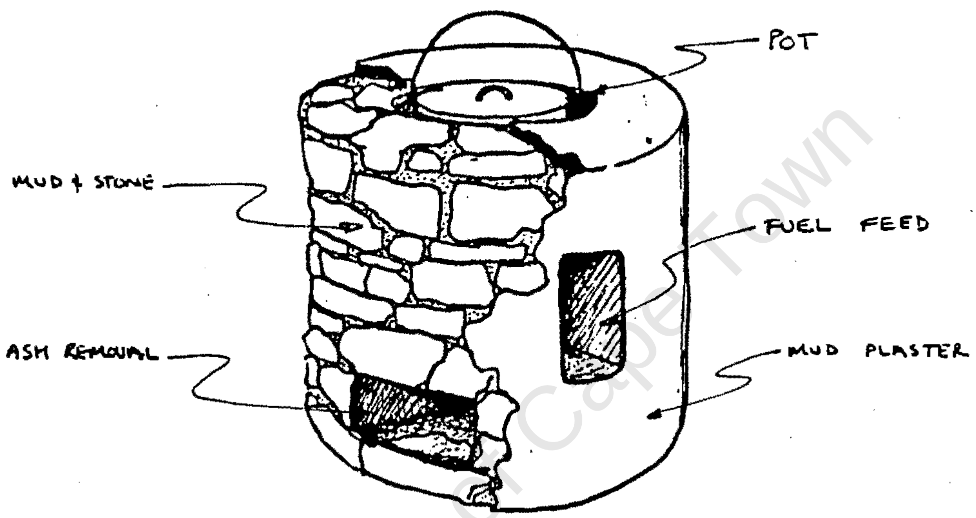


For the stoves to be truly fuel efficient, certain critical dimensions such as the depth of the fire-box must be adhered to in the building of the stove. This is often difficult for owner-builders and can to an extent be overcome by building the stove around removable wooden moulds, or around permanent metal or ceramic inserts.

The major disadvantage of this type of stove is the time and effort that the owner-builder must invest in building the stove in relation to the stove's limited lifetime. Some programmes train a member of each household, while others concentrate on training only a few builders who then travel through their area building stoves for a small fee. The limited lifetime of the stove is due to the stove body cracking, particularly if incorrect sand/clay proportions are used. However since available materials differ from place to place, the correct mixture can only be determined through trial and error. Heavy mass stoves generally have a low efficiency for short cooking operations because the large mass absorbs much of the initial heat from the fire. Efficiencies of high-mass mud or brick stoves range from 10 to 24 percent.

Local designs include the <u>Stone Paola</u> promoted by the Lesotho Government. This is a cylindrical stone and mud structure built around a metal grate and pot-rest which accommodates the commonly used cast-iron three-legged pot. Openings at the base of the structure allow fuel feeding and the control of air flow. The stove is reported to use only half of the wood used in an open fire and has had some success with rural housewives (Law & Eberhard,1990).

Figure 4.4.2. The Lesotho Stone Paola

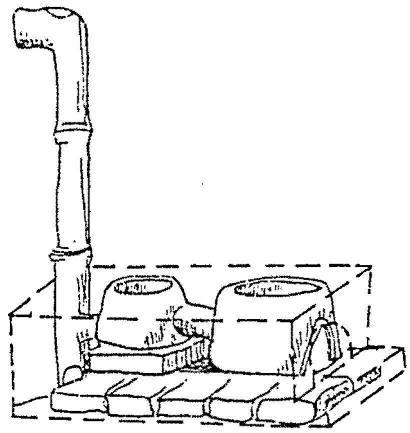


Organisations in Zimbabwe have had some success with disseminating metal kits for mud stoves and in training people in the craft of mud stove construction. Mud stoves have also been introduced into to the Transkei and northern Transvaal.

Ceramic Liners

A system popular in Indonesia is the use of ceramic stove liners. These consist of two or three inter-connecting ceramic cylinders, generally hand-made by local potters. The first cylinder forms the fire-box, and subsequent ones form the pot rests. The flue gas from the fire-box is forced through the inter-connecting pipes to the other cylinders and finally up the chimney. Cooking pots rest on top of each cylinder.

Figure 4.4.3. The Indonesian Magan Chula

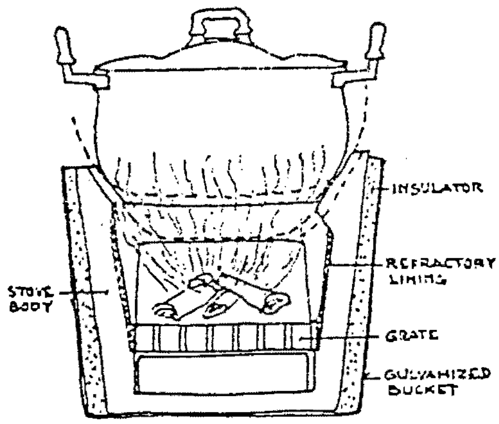


The liner assembly can be used as a portable stove or can be insulated by building a mud/clay structure around the outside. Ceramic liner stoves are rather brittle but will last well if used with care. If used in a mud stove they can potentially increase both the efficiency and the durability of the normal mud stove.

<u>Portable Single-pot Stove</u>

These stoves basically consist of a cylindrical metal or ceramic housing which surrounds the hearth and grate and on top of which is mounted the pot. These light-weight stoves were originally used as charcoal burners but more recently have been modified to operate with wood. The portable single-pot stoves have been shown to give the highest cooking efficiencies and the greatest saving in wood, with reported efficiencies between 10 and 35 percent. However, they are not very durable and parts may have to be replaced every two or three years. A further disadvantage is that they do not remove smoke from the cooking area and can carry only one pot at a time. The Thai-bucket shown below is a typical example of its type.

Figure 4.4.4. The Thai Bucket Stove



Modifications to the basic construction include controllable air intakes, ceramic-metal combinations and double-skin metal construction where the space between the two skins is filled with an insulator such as clay, soil or vermiculite. A typical example of this stove type in South Africa is the ubiquitous metal drum with perforations in the sides, generally used as a space heater. Improved local designs include the charcoal burning, ceramic "Mbaula" in Malawi and the "Basic Tsotso" in Zimbabwe (Law & Eberhard,1990).

Multi Pot Metal Stove

There are a large number of stove designs, including most commercial wood/coal stoves, that fit into this category, which can be further divided into light-weight (sheet metal) and heavy weight (cast iron) stoves. Essentially, they consist of a deep fire-box in which the fuel is burned, connected to a chamber through which the flue-gas is passed before rising up through the chimney. The fire-box and flue-gas chamber are covered by a thick metal plate, large enough to accommodate two or three pots. Some designs have holes in the stove top into which pots can be sunk. The stoves are generally made of cast-iron or mild steel sheet and may include improvements to the basic design such as primary and secondary air control, insulation of the stove walls and careful design of the flue-gas passage for maximum heat transfer.

Multi-pot metal stoves are the most sophisticated and thus most expensive fuel efficient stove type, and because of their cost, may not be widely used in poorer areas. An advantage of the light-weight construction is that it could be manufactured in small rural workshops. However, the thin sheet steel is not very durable, particularly where the metal is exposed to flames. This problem may be overcome by incorporating ceramic liners.

Figure 4.4.5. The Lesotho Mabotle Metal Stove

The bulk of commercial wood stoves available in South Africa are made from cast iron with an enamelled finish. While they are very durable, they are also very expensive and are generally not used widely in the rural areas. The commercial stoves have generally not been designed around fuel efficiency and in many cases have efficiencies lower than an open fire. There is potential in some countries, particularly South Africa, for a hybrid light/heavy weight stove. Certain high temperature parts could be factory-made from durable cast iron and the whole stove assembled by local artisans in village workshops.

4.4.4. Stove Dissemination Programmes

One of the first programmes for "improved" stoves aimed at saving wood, began in India in 1947 with the development of the Magan Chula. This stove was based on traditional chula and was in many respects, the direct precursor of the Lorena stove. Various research institutes in India continued this work into the 1950s and 1960s, producing some 50 different designs by 1964, the most notable being the mud/brick HERL Chula which established the basis of stove design in a number of other countries (Foley et.al.,1984:59). Also from India came the idea of local potters selling ceramic stove parts, which were then joined together and the whole assembly embedded in a mud or clay body.

Other early stove programmes were initiated in Indonesia and Ghana but with limited success, and it was not until the development of the Lorena Stove in the wake of the 1976 earthquakes in Guatemala, that fuel efficient stove programmes really took off. The Lorena stove continues to be promoted in Guatemala. Similar "owner-built" types, as well as artisan or factory built metal stoves continue to be disseminated, with varying degrees of success, in a large number of developing countries throughout the world.

One of the main areas of benefit usually expected to emerge from fuel efficient wood stove dissemination programmes is a decrease in deforestation. However, the link between fuel efficient stove use and deforestation is tenuous, and many stove programmes have failed partly because they have focussed on this as an objective. The reasons for deforestation are many, and unless it can be absolutely established that <u>all</u> the wood from felled trees is used for domestic cooking, justification for a fuel efficient wood stove programme has to be found elsewhere.

A more tenable goal for stove programmes is to aid the increase in living standards through improved conditions in the kitchen. However, the health, safety and efficiency advantages of a stove over an open fire are not always obvious, or highly attractive to rural people. Only when people see and appreciate these benefits and rate them greater than the costs, will stoves be adopted. This is the crucial test for all stove dissemination programmes. The success of stove programmes has to be found in their capacity to deliver these direct benefits to the people who will use them, and since the stoves will be used, it is sensible that they be designed to use wood as efficiently as possible.

The number of households using wood is too great for an external agency to construct and supply every stove, and for stove programmes to have any impact, they have to become self-sustaining. A stove dissemination workshop in 1981 produced a list on nine steps to be implemented in that order for the successful dissemination of wood stoves (Foley et.al.,1984:81). These steps are:

1. An initial needs assessment;
2. Development of stove design criteria based on the assessment;
3. Modification of existing stoves or design on new ones;
4. Laboratory testing of the stoves;
5. Field programme to test performance and acceptability of the new stove;
6. Monitoring and evaluation of the field programme;
7. Further design work if new stove is not satisfactory;
8. Development and appraisal of methods of manufacture;
9. Design and implementation of large-scale dissemination programmes.

If a fuel efficient, or "improved" stove is being introduced into a strong market situation, or perhaps in competition with traditional stoves already sold and used widely, dissemination can be based on the existing manufacture and marketing structure, with the new stoves ultimately becoming part of this system. The new stove will obviously have to be an improvement on its traditional competition. Again an accurate needs assessment is required so that the improvements are ones that the users need, rather than ones seen by the designers. The fact that the improved stoves are more fuel efficient is seldom enough to stimulate a mass demand for the new stoves. Additional features such as appearance, low-cost and durability are usually required.

A slightly different approach may be required in areas not operating on a cash economy in any significant way, or where the demand for stoves is weak.

Dissemination under such circumstances is usually very difficult. One approach is to design and introduce "no-cost" stoves which can be built by the user with freely obtainable materials. No-cost stoves must be easy to build, and their performance must not depend too heavily on construction to strict specifications. Typical no-cost stoves are those built by rural villagers from mud/clay/sand mixtures. One of the main disadvantages of this type of stove is their inclination to crack and crumble within a short time of being built. Some programmes have alleviated this problem by substituting the clay/sand mixture with bricks and mortar, although this pushes the price up and requires special skills to build. But there is another side to the dissemination of owner-built stoves, as a field worker in Senegal noted:

> "Despite the somewhat short life expectancy (of the stove), all the preliminary work, organisation and participation that leads to the actual (stove) construction is an accomplishment worth noting in terms of community development. Women can realise a goal in a new domain and the skills they acquire in doing it can then be used in the future." (in Foley et.al.,1984)

Although all stove programmes need to be self-sustaining in the long run, they involve some degree of subsidy in setting up, developing prototypes, advertising, and training and reimbursing extension workers. Local conditions may also require that the manufacture and distribution of the stoves has to be subsidised. In order to justify the level of subsidy, the costs of a stove programme need to be matched against the potential benefits that would result. However the potential benefits of a stove programme are difficult to quantify, particularly in the absence of a direct link between the use of fuel efficient stoves and a reduced rate of deforestation. Like many other development programmes which ultimately aim to fulfill basic needs, provide opportunities or improve living standards, the benefits to the national economy are very long term and almost impossible to justify with traditional economics.

4.4.5. A South African Case Study

Stove dissemination programmes in South Africa have lagged far behind developments in the rest of the continent. In southern Africa, stove programmes with various degrees of success have been implemented in Zimbabwe, Lesotho and Botswana but in South Africa itself there has been no large-scale programme. In 1981, the Environmental Development Agency, based in Johannesburg, introduced a number of Lorena-type stoves in the northern Transvaal and Transkei, and also produced a booklet guide to Lorena stove building. Prior to this, the KwaZulu Development Corporation did some preliminary work on a single-pot light weight metal stove, but it appears that this research did not progress very far. The Transkei Appropriate Technology Unit has also experimented with various stove designs, but have only put a handful of stoves into use.

In 1985, the Energy Research Institute (ERI) at the University of Cape Town embarked on a National Energy Council sponsored project to develop a low-cost fuel efficient stove for rural areas, the full report of which can be found in Dickson & Baldwin (1990). In order to determine the requirements of potential users, surveys on cooking practices and stove usage were conducted in KwaZulu and Natal and information drawn from previous energy surveys. The survey information, which included households using commercially available wood/coal stoves, noted types of food commonly cooked, cooking methods, and types of pots commonly used. The survey also showed that fuel efficiency was not a very strongly perceived need. The most important requirements of a stove were listed as:

- the ability to cook more than one pot simultaneously;
- the removal of smoke from the cooking area;
- the inclusion of an oven and hot water tank;
- the space heating function; and
- strength and appearance.

Based on the surveys, information in the literature, and the specification that the stove should be manufactured in rural workshops, the ERI designed and built two prototype stoves, a chimneyless single-pot stove and a two-pot stove with chimney. Both stoves were of sheet-metal construction with a fireclay/vermiculite insulating layer, and were designed to accommodate the commonly used three-legged cast iron pots. The prototypes were extensively tested in a laboratory and redesigned to obtain the best fuel efficiency. Laboratory testing showed an efficiency of 55% for the single pot stove and 40% for the two-pot stove.

In subsequent field trials the single-pot stove was not well received, because it appeared to the users to provide no advantage over an open fire. This prototype was discarded and further work was concentrated on the two-pot stove. The initial field trials indicated that the two-pot stove users consumed about 14% less wood than households using open fires. There were however problems with the durability of the sheet metal, and many users expressed the desire for an oven which this model did not have. The stove was redesigned to overcome these problems.

One of the constraints on the design was the specification that the stove be manufactured in rural workshops. However, initial investigation showed that the stove would be too complex for rural workshops and too expensive if factory manufactured. The cost of the stove if manufactured in rural workshops could not be determined although quotes from two small engineering works ranged from R370 to R500 per unit ex-factory. It was decided to reassess the basic approach to the project and the feasibility of large-scale manufacture was investigated. Falkirk, the major manufacturer of solid fuel stoves in the country was approached and agreed to collaborate in the design of a further prototype. The emphasis was to improve durability, reduce costs and to investigate a "stove-top" oven which could be offered as an optional extra. The sheet-metal construction was changed to an enameled sheet steel body with a 20 mm internal refractory cement lining, and a fire-box, baffle and hob of cast iron. The design would allow factory mass production and could thus be retailed at a low cost through conventional commercial channels. The efficiency of the final design was shown to be about 30% and the ex-factory cost estimated at R235. This could be reduced to around R180 with factory mass-production.

While the durability problem had been overcome, field trials with the third design showed still no evidence of a substantial wood saving. This was attributed in part to the difference in the way the stove was designed to be used and the way in which it was actually used in the field trials. Despite this, Falkirk have retained an interest in mass-producing and marketing the stove in the future

With the single-pot design abandoned and the two-pot stove costing more than the desired target price, the ERI felt that a gap still existed in the market for low-cost fuel efficient stoves. This prompted the development of a hybrid mud/steel stove which would eliminate some of the common durability problems associated with Lorena-type (mud only) stoves while still keeping costs to a minimum. Metal components of the prototype design consisted of a 5 mm sheet steel hob, a sheet steel door, and a grate consisting of two standard cast iron drain covers. The stove body could then be built from any readily available material such as mud, clay/sand or brick. A sheet steel or asbestos pipe could be used as a chimney. The raw materials cost of components was estimated at R86, bringing the total "manufactured" component cost to R100. The materials and labour cost of the stove body would obviously depend on individual circumstances. Standard laboratory tests gave an efficiency of 28%.

A migrant worker from the Transkei obtained stove parts from the ERI and installed a stove in his home without any on-site assistance. The stove was in daily use for a number of years and seemed to perform well. Interest from the local population prompted the original owner to request more stove components, and a further 15 stoves were transported to the Transkei and sold to the original owner at a subsidised price of R80 with a further R8 for transport. The owner then built a number of stoves and sold them (at a price determined by himself) for R200 each.

Although there were problems with this "ad-hoc" dissemination method (including the high cost of the stove), it was felt that this type of design has a lot of potential in rural areas and a more concerted dissemination effort is planned for the future.

4.4.6. The Potential for Fuel Efficient Stoves

South Africa is in a seemingly good position for the widespread dissemination of fuel efficient stoves to rural households. There is sufficient expertise to research and develop suitable stoves, and a well developed industrial sector which could provide them, or the materials for their construction at a reasonable cost. There is also a good network of government and non-government organisations which, if adequately funded, could provide training on stove building or stove use. The fuel efficiency of an open fire is typically around 10%. At best, a well designed metal stove can have an efficiency of around 35%. Theoretically then, to complete the same cooking tasks, a fuel efficient stove will use approximately 30 kg wood to an open fire's 100 kg. Thus, if each wood-using rural household in the "homelands" was supplied with one of these stoves, the 1990 fuelwood consumption of around 7 million tonnes per annum would, theoretically, be reduced to around 2.1 million tonnes per annum. In addition to this, health problems associated with woodsmoke, soot and burns would be a thing of the past and households could look forward to cleaner, more manageable kitchens and an improved standard of living.

However, there are a number of practical constraints, technical and social, which make this scenario somewhat optimistic.

- The fuel efficiency of a stove is measured and compared in the laboratory according to standard tests. These give no quantitative indication of the fuel consumption of the stove under real conditions. This depends on types of food cooked, methods of food preparation and how the stove is used, and the real potential of a stove to save fuel can only be measured by long-term monitoring of comparative household using fuel-efficient stoves and traditional open fires.
- Fuelwood savings, as mentioned above, are as dependent on the user as on the rated "efficiency" of the stove. A fuel efficient stove may increase fuelwood consumption if it is used more often, or if it is not used as designed. The dissemination of woodstoves must be accompanied by education in energy conserving cooking methods.
- There is a wide range of well made, attractive commercial wood stoves available in South Africa. However, these stoves are seldom fuel efficient, nor is their

distribution accompanied by education in the use of energy resources. The stove manufacturing industry has also little interest in fuel efficiency or in the establishment of community based workshops for woodstove building. Unless fuel efficiency is widely recognised as desirable, a new design would face stiff competition.

- The dissemination of low-cost or no-cost fuel efficient stoves necessitates the establishment of organisations and structures willing (and with sufficient funds) to undertake such a project.
- Most importantly, the rural population must be concerned about deforestation and committed to stoves as being a viable solution. The stoves in turn must provide tangible benefits to the users.

There are a number of ways of reducing the consumption of fuelwood. Providing rural households with fuel efficient stoves is one way but may not be the best in terms of results, nor the most optimum in use of resources. Few of the many stove programmes can really claim to have reduced wood consumption. Most measure success in terms of the number of stoves disseminated and seldom provide follow up studies sufficient to meet the requirements of basic statistical analysis (Foley et.al.,1984). What is most important to note is that it is the reduction of fuelwood consumption, not the problems of fuel efficient stove design, that is the real challenge.

4.5. Biogas

4.5.1. Introduction

Biogas is a naturally occurring gaseous product of the anaerobic fermentation of organic material and consists primarily of methane and carbon dioxide. The anaerobic fermentation process has been used for some time in the wastewater treatment industry with the primary purpose of sewage stabilisation but use of the process as a generator of useful energy in rural underdeveloped areas is more recent and has been pioneered in China and India. There are a number of different types of digestor designs, but the basic operation is the same. Organic waste is fed daily, displacing an equal volume of treated slurry. The gas produced by the fermentation, is stored under pressure in the reactor or in a separate tank and is drawn off through a filter and piped to a burner. As a fuel, biogas can be used in much the same way as commercial LPG and can be used directly for cooking, heating or lighting. It can also be used to run a refrigerator or, in combination with diesel fuel, run a diesel engine.

Biogas has been seen by some as an obvious answer to the energy problems facing rural areas in that the anaerobic fermentation produces a highly versatile fuel while at the same time stabilising human and animal wastes for use as a fertiliser. There are however, certain requirements for the successful operation of a biogas digestor:

- A continuous supply of animal waste is required as feed for the process. Animals thus have to be penned or the dung manually collected.
- Large quantities of water are required to dilute the waste.
- The process is temperature dependent and is therefore not suitable for cold climates without some sort of heating arrangement.
- Construction of digestors requires a specific skill and considerable capital. The digestors need to be gas-tight and generally require continual maintenance.
- Operation of the digestor requires a high degree of commitment.

Apart from the difficulties of introducing a "new" technology, the conditions above would not apply in many parts of rural South Africa. However, the success of biogas programmes in other parts of the world have been considerable and biogas as a fuel supply for underdeveloped areas remains a promising renewable energy alternative.

The two countries which stand out in the field of biogas development are China and India, and in terms of assessing the potential for South Africa it is pertinent to examine some aspects of the history of their development. Firstly and most importantly, both the Chinese and Indian biogas programmes were undertaken with intense involvement and support from state departments. The assistance covered finance, the training of builders and operators, and the education of local villagers. At another level, universities and state institutions were involved in research and development which fed directly into the rural programme. Secondly, the intensive agricultural practices in these two countries (particularly pig-farming in China) favoured this kind of technology.

There are reportedly some 7 million digestors in China, mostly "family-sized" and in rural areas. In addition to family biogas units, there are in China some 715 biogas power stations and 617 biogas generator plants supplying power to small villages and sections of larger towns (Chen Ruchen,1981). Another estimate maintains that biogas contributes as much as 27% to China's total energy use (Flavin,1985). Between 1974 and 1978 an estimated 7 million digestors were built but by 1982 it was apparent that only about one-third of these were operating reliably. Initially, the main emphasis in the Chinese programme was on keeping down construction costs, resulting in badly made, leak-prone digestors and the necessity for training large numbers of maintenance personnel. There has recently been a concerted effort by the Chinese authorities to revive dormant biogas digestors and to proceed with new ones at a more cautious pace. India on the other hand, concentrated its programme on reliable and more costly designs with the result that the benefits of biogas became available only to the more wealthy farmers. India has approximately 100 000 digestors installed. Other countries with large biogas programmes are South Korea with 29 000 and Brazil with 2 900 (Kristoferson & Bokalders,1986).

In South Africa, anaerobic digestion research has been limited to the wastewater treatment industry where gas production is not the primary aim. The most impressive biogas work has been the occasional attempts of individual farmers (cf. Fry,1974). There has been virtually no support from state authorities or academics and at one stage the most authoritative forum on biogas in South Africa was the Farmers Weekly. There have also been a number of biogas digestors built in neighbouring countries under various programmes which will be reviewed below.

4.5.2. Anaerobic Digestion and Biogas Digestor Technology

The production of biogas results from the anaerobic (without oxygen) fermentation of organic matter. In the process, certain bacteria "feed" on the organic material producing as by products of their respiration, methane, carbon dioxide and heat. Biochemically, the process is fairly complex involving a range of different bacteria and fungi, and it is highly sensitive to process instability. Small amounts of oxygen in the system and rapid temperature changes of as little as 3°C are enough to destroy the microbial population. The fermentation can be operated either as a batch or a continuous process and in general, the latter is favoured as it produces a continuous supply of gas. Design and operating parameters most important to the successful production of biogas are given below:

- Organism activity is directly related to temperature. Control is important and digestors are usually built underground or are insulated with earth banks.
- The residence time is a measure of how long the bacteria remain in contact with the feed. This is determined by the relation between the size of reactor and the volumetric feed rate. Methane producing bacteria are slow growers and too small a volume or too high a feed rate will cause wash-out of the organisms.
- Organisms need nitrogen for growth. The carbon/nitrogen ratio of the feed should ideally lie between 20:1 and 30:1.
- The digestor must be gas-tight. This is important to prevent loss of gas and influx of atmospheric oxygen.

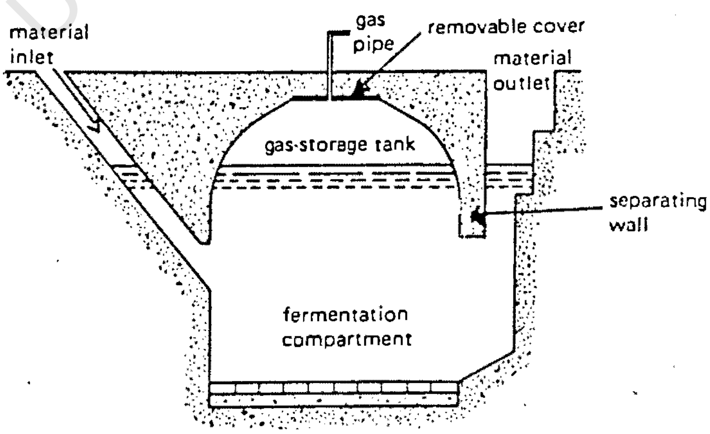
The amount of biogas produced is dependent on the quantity of feed and its retention time in the digestor, which in turn determines the digestor size. Household plants are usually around 8 to 10 m^3 while community scale plants can have capacities over 40 m^3 (Kristoferson & Bokalders,1986)

There are three main types of biogas digestors applicable to the underdeveloped rural situation: the fixed-dome (Chinese type), the floating cover (Indian type), and the bag or plug-flow type.

The fixed dome

The fixed dome consists of an airtight container constructed of brick, stone or concrete, the top and bottom being hemispherical and the walls straight. Construction is fairly simple and entails digging a hole into the ground and lining it with several layers of mortar. Difficulty is often experienced in constructing a gas-tight roof. Concrete construction uses a novel method whereby a circular trench of specified diameter, depth and width is dug in the ground. After securing reinforcing, the concrete mix is poured into the trench and over the top of the ground enclosed by the trench, leaving space for a manhole. When the concrete has cured, the enclosed earth is dug out through the manhole and the floor is cast.

Figure 4.5.1. Fixed Dome or Chinese Type Digestor

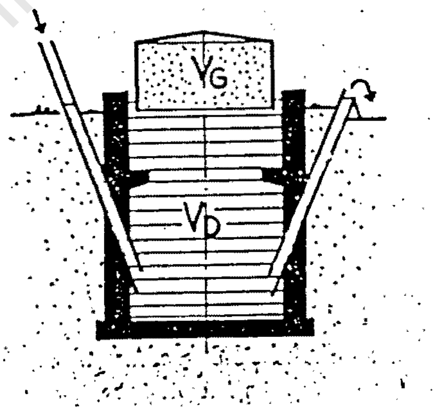


The digestor is fed on a semi-continuous basis with animal manure, nightsoil and agricultural waste, and regular quantities of sludge are drawn of to maintain the correct level. Feed and draw-off pipes are positioned so as to provide a water-seal. Gas is drawn off through an opening in the roof and is sometimes stored in an intermediate container. Gas production is typically 0.1 to 0.2 volumes of gas per volume of feed and the average retention time in the system is about 60 days at 25°C. The pressure of the gas depends on how much is drawn off, with the pressure decreasing as the gas is used.

<u>The floating dome</u>

The floating dome digestor was developed by the Khadi and Village Industries Commission in India. It consists of a cylindrical container of height-to-diameter ratio of about 2.5 to 4:1 dug into the ground and built of brick and mortar or wire-reinforced concrete. Gas rising through the liquid slurry is caught by a floating mild-steel cover shaped like an inverted cup, which holds the gas and maintains a liquid seal. Waste is fed on a semi-continuous basis through a water seal displacing an equal amount of slurry through an outlet pipe.

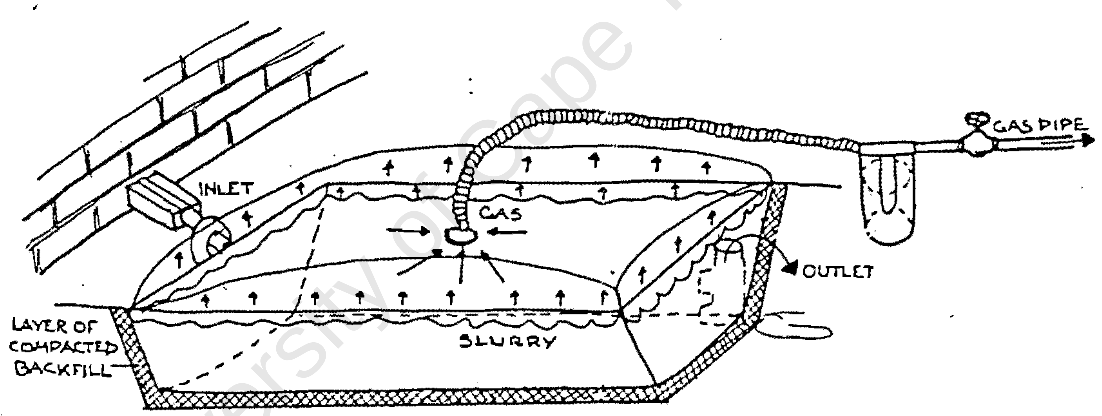
Figure 4.5.2. Floating Dome or Indian Type Digestor



Retention times are typically between 30 and 50 days depending on the temperature and gas yields are about 0.2 to 0.3 volumes of gas per volume of feed. Gas pressure remains constant, (depending only on the weight of the steel cover) and is typically between 4 to 8 cm water pressure. The floating dome type is considerably more expensive to build than the fixed dome type.

<u>The plug-flow digestor</u>
The floating dome type consists of a long, usually horizontal cylinder of brick, concrete, PVC or plastic. Feed is introduced at one end and spent sludge removed at the other. Gas is removed from the outlets along the top of the cylinder. This type is often the most costly to construct but gives highest gas production rates.

Figure 4.5.3. Plug-Flow Type Digestor



A cheap version of the plug-flow digestor is the "bag" digestor. This consists of a flexible, cylindrical plastic tube incorporating the feed inlet and slurry outlet pipes at either end, and an outlet pipe for the gas. The transparent plastic allows day-time sun to heat the contents and for insulation, the bag is usually laid into a shallow trench in the ground. A complete 50 m^3 system can weigh just 270 kg. The digestor is fed semi-continuously, displacing an equal amount of slurry through the exit pipe. The gas produced collects inside the flexible bag and is drawn off as required. Typical retention times are 20 - 60 days, and gas production rates of between 0.23 and 0.61 m^3 gas per m^3 feed have been recorded.

This listing by no means covers all digestor types and there are a number of variations being developed with a view to lowering construction costs and improving reliability.

4.5.3. Biogas Activities in Southern Africa

Since there has been so little work in South Africa on biogas digestion as a fuel source for underdeveloped areas, the following section will include case studies for some other southern African countries. Biogas programmes in southern Africa have been reviewed in Rivett-Carnac (1982) and in Williams & Eberhard (1986). The bulk of the information below has been taken from a directory of rural energy projects in southern Africa by Eberhard (1984), and a yet unpublished update by Law & Eberhard (1990)

<u>South Africa</u>

Biogas activity in South Africa is at present almost non-existent, apart from occasional single-handed attempts by farmers. One of the pioneers of biogas technology in South Africa was former pig farmer, L.J. Fry. He perfected a horizontal plug-flow reactor which was fed with waste from his piggery and was used to run a 9.7 kW Crossley slow-running diesel engine converted to spark ignition which in turn powered a 6 kVA alternator and a 6 kW generator. Fry attempted to promote his ideas through the agricultural authorities, but without any success (Williams & Eberhard,1986). Another pig farmer, N. Steyn built a large 136 m^3 digestor fed with pig and cattle manure. At full capacity, the system ran a 4.5 kW dual-fuel converted Lister engine for 12 hours/day, but has since developed leaks and is running below capacity (Williams & Eberhard,1986). A number of other digestors have been built on rural locations, but these function primarily as sewage treatment plants.

Some work has been done at the University of the Witwatersrand on the suitability of biogas as a diesel-fuel substitute for small-scale electricity generation.

Botswana

Initial experiments were carried out by the Rural Industries Innovations Centre (RIIC) on three different digestor designs, namely the floating-dome or Indian type, the Chinese type and the horizontal plug-flow type. This work identified the floating-dome type as being the most appropriate to conditions in Botswana. An initial economic assessment also showed that biogas production is most favourable for borehole syndicates, commercial farms and cattle posts (in that order). By July 1988 there were 13 biogas plants in operation. Plants at Diphawana (75 m^3) and Mogwalale (120 m^3), both run by borehole syndicates, have a unique symbiotic relationship with the cattle they water. Dung collected at the borehole is used to feed the digestors which then produce enough gas to run diesel powered water pumps to water the cattle. The Diphawana installation has been running satisfactorily since 1983, producing gas at an average of 23.6 m^3 per day which is used to run a converted Lister diesel engine pumping 38.6 m^3 of water per day from a depth of 78 m. It is claimed to be one of the few successfully operated biogas plants in Southern Africa (Williams & Eberhard,1986). There is great potential for this type of installation given Botswana's estimated 4.6 million head of cattle and the fact that deep boreholes provide almost all the watering needs of the livestock. Steps are being taken to construct more such plants in Botswana under the guidance of the RIIC, based on the success of the Diphawana borehole trials.

Other digestors used for water pumping are at Kgotswane and Kang. Biogas is also being used at the Kang Brigades to heat an oven for bread baking and at the Kang clinic for cooking.

RIIC has produced a full set of plans and building instructions for floating-dome digestors of up to 45 m^3 as well as a "Maintenance and Operators Manual". There is a demonstration digestor at RIIC which is also used to provide gas in order to test various appliances for suitability and modification. The test section includes a diesel engine (with a modified air inlet which runs on a 80/20 biogas/diesel mix), various stove burners, gas lights and a gas refrigerator. These appliances are being tested and modified with the aim of producing models that can be locally manufactured.

Lesotho

Biogas technology was first introduced in Lesotho in 1982 through two projects, one funded by UNESCO and coordinated through the National University of Lesotho (NUL), and the other funded by the UN's Food and Agricultural Organisation (FAO) and coordinated through the Ministry of Agriculture. Funding and technical support from these sources was terminated in 1985. The biogas programme under the Ministry of Agriculture was extended until the end of 1987 with financial and personnel support from the Government of China and some research work is still being done at the NUL.

There was a clear preference in the UNESCO/FAO biogas programmes for the Chinese-type digester. The chief advantages were seen as low construction costs and better ground insulation, and therefore higher temperatures and gas production during winter. The results of the UNESCO and FAO programmes were not very promising. Of the 24 digestors built between 1982-86 inclusive, only seven were operating by March 1987. With extended Chinese support (including assistance from three Chinese biogas experts), a further 10 digestors were built in 1987 and 10 masons trained.

The dissemination strategy in Lesotho has been to build as many digestors (and train operators, masons etc.) as possible in each of the 8 Districts and in this way spread the technology through a "demonstration" effect. It is possible that the rush to build digestors while support was available led to a lack of research into the attitudes of villagers towards this technology and little dissemination of information about its benefits. In 1988, of twenty-two biogas digestors surveyed, 16 were inoperative supposedly due to improper handling, lack of maintenance, lack of time available on the part of the villagers for running the digestor, and lack of basic information on the operating principles of biogas.

Although the Agricultural Ministry and the University are still engaged in some research work, the Department of Energy has advised against the active promotion of commitment and institutional support, as well as suitable animal husbandry methods. Closer to home, the success of the borehole installations in Botswana, results from a carefully targeted and well researched approach. The opposite happened in Lesotho where and over-ambitious programme resulted in the building of 30-odd communal digestors, of which only a handful still operate.

Biogas programmes in the South African "homelands" would face similar problems to those identified in the Lesotho case study, particularly with respect to methods of animal husbandry and access to water. In areas where wood is still collected as a "free" resource, it would be difficult to persuade people to invest in a biogas digestor, especially where there is no technical backup. The obvious applications would be larger community situations that at present have to buy their fuel, such as schools, hospitals etc. However, in these instances where the feedstock is purely human waste, some way of increasing the low C:N ratio would have to be considered.

As has been experienced in India, the cost of the systems and the requirement for a large number of livestock per family, mean that biogas is an option only for the relatively well-off rural families. Nevertheless, there are situations where biogas systems will work favourable and where they will pay for themselves in a relatively short period. Such cases need to be investigated.

4.6. Solar Cookers

4.6.1. Introduction

Perhaps the greatest proportion of firewood burned by households in rural underdeveloped areas goes towards providing energy for cooking. While it is unlikely that this traditional fuel will quickly or easily be replaced, cooking devices using alternative energy sources could certainly alleviate the heavy dependence on firewood. Although solar cookers have some disadvantages, they are cheap, simple to build and simple to use. Also, the abundance of sunshine in most parts of South Africa makes them particularly attractive, and they are safe, non-polluting and use a renewable energy resource.

The earliest accounts of solar cooking date back as early as 1767, but it was only in the late 1940s in India, that developments in solar cooking technology were directed towards solar energy as a substitute for traditional rural fuels (Pinon,1983). Since then, technical refinements have continued and a number of programmes to introduce solar cooker technology into rural and underdeveloped areas have been initiated. However, intensive programmes in India, Mexico and Morocco, have so far not had much success. Failure has usually been accredited to problems associated with the technology or with the rural socio-economic background, but it is also clear that the way in which the technology is developed and transferred to these communities is often the cause of failure (Pinon,1983).

Locally, there has been very little research into solar cookers for underdeveloped areas. What has been done does not seem to have yielded very favourable results, but this is largely a reflection of the lack of dissemination effort than some intrinsic characteristic of solar cooking technology.

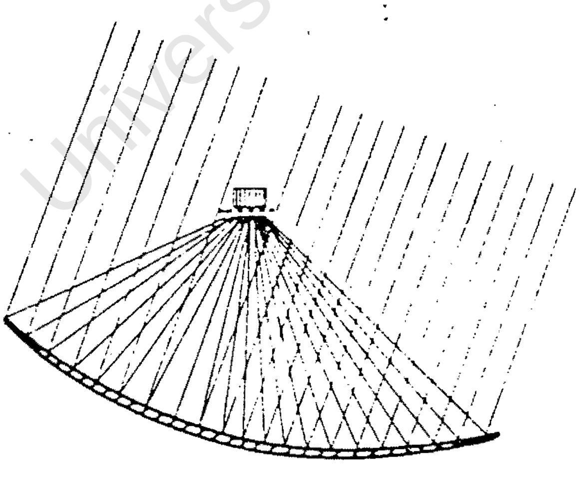
The following section will discuss some of the different solar cooker designs, the economics of solar cooking, and will examine some case studies undertaken in southern Africa.

4.6.2. Solar Cooker Technology

In principle, the solar cooker is a simple device which gathers solar radiation over a large area (the collector), and concentrates it onto a small area (the pot). Using the same principle, solar cookers can be either stoves or ovens. The wide range of different designs of solar stoves and ovens can be classified into two distinct groups, one type uses direct solar radiation, i.e. the sun's rays are concentrated directly on to the cooking pot, and the other, indirect, where a heat transfer fluid is used to transfer energy from a solar collector to the cooking vessel.

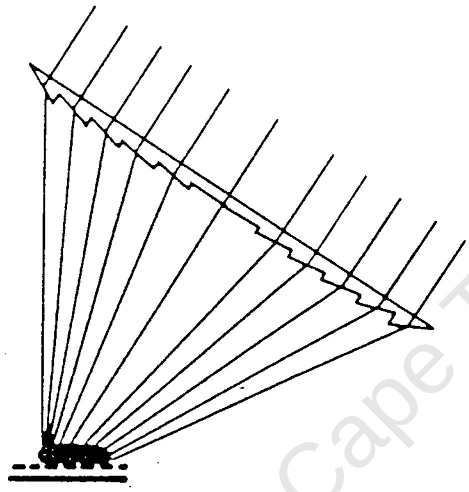
Direct radiation cookers can further be classified into essentially three different types. The reflector type uses a single or series of curved or angled mirrors to focus the suns rays onto the sides or bottom of the cooking pot. They usually have a parabolic or trough-shaped mirror facing upwards with the cooking vessel suspended at the focal point.

Figure 4.6.1. Reflector-type Solar Cooker



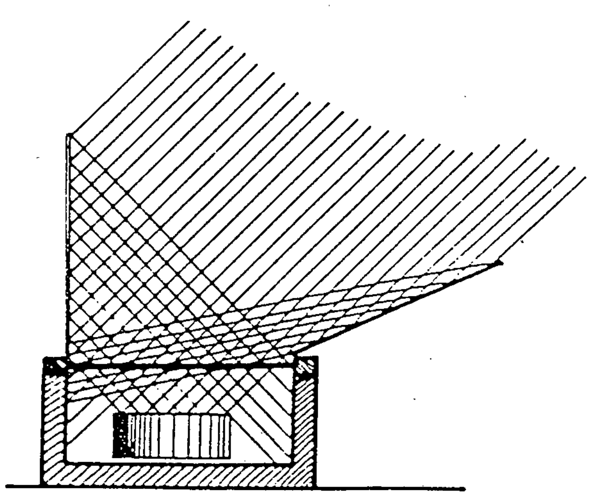
The refractor or fresnel type refracts the rays of the sun through a special lens to focus on the cooking pot. In this case the lens is placed between the sun and the cooking vessel.

Figure 4.6.2. Refractor or Fresnel Type Solar Cooker



The oven type uses flat, angled mirrors to direct the sun's rays into a glass-lidded, insulated box into which the cooking vessel is placed. The mirrors are generally flat plates of polished metal which do not have a focal point but direct rays through the glass lid and into the oven compartment. The high temperatures required for cooking and baking are achieved by a combination of solar energy concentration and greenhouse effect. In other words, by insulating the oven compartment, convective heat and heat re-radiated from the cooking vessel is trapped.

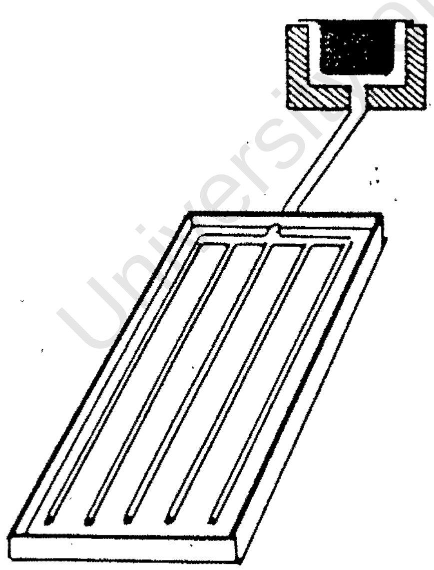
Figure 4.6.3. Oven Type Solar Cooker



Direct solar cookers have the advantage that they can often be designed to fold up when not in use and require no maintenance except for the occasional polishing of the mirror surface. Their main disadvantages are that constant attention is needed to keep the focal point on the pot, they are useless on cloudy days and after sunset, and, excepting the oven type, their performance is severely diminished by the cooling effect of wind.

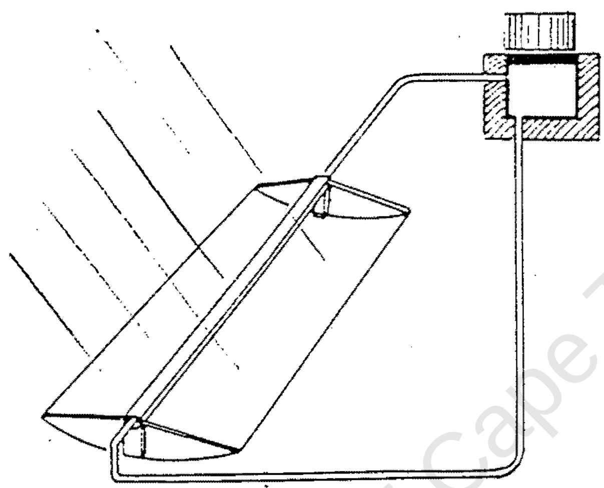
The indirect solar cooker is a more recent development which uses a solar collector panel to heat a fluid which is then piped to a the metal hot plate or a stove arrangement. One type uses water in the collector which is then converted to steam and piped to an insulated cavity in which the cooking vessel is placed.

Figure 4.6.4. Open-system indirect solar cooker



Another more sophisticated type uses a heat-transfer fluid in a closed circuit. The fluid is heated in the collector and piped to the hot plate, replacing cooler fluid which returns to the collector panel.

Figure 4.6.5. Closed-system indirect solar cooker



The advantages of the indirect system are that the heat-transfer fluid can retain the heat collected in the day so that the stove or oven can be used after daylight hours and that, with minimal plumbing, the stove assembly can be placed indoors with the collector outside or on the roof. Also it is not necessary to continually reorientate collector panels during the cooking process. Some indirect systems have been designed to function as solid fuel stoves as well. The major disadvantage of the indirect system is its increased complexity and cost. Repairs and maintenance may also require some skill.

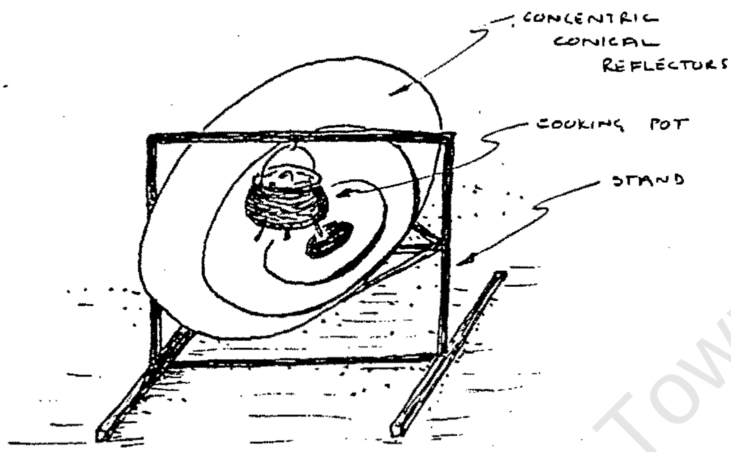
Solar cooker design essentially depends on optimising the collector surface area so that a variety of foods can be cooked in an acceptable time period. It is therefore necessary to understand the cooking process. Cooking of food is performed by subjecting the food to temperatures sufficiently high for the necessary chemical and physical changes to occur. Different cooking processes require different temperatures. Meat and fish require internal temperatures of around 70°C, while the surface of roasts can be as much as 140^{o}C and baking is usually done at around 150^{o}C. Water boils at 100^{o}C or less, depending on altitude. The energy required to cook food also depends on whether the steam driven off in the heating process is trapped in the pot or is allowed to escape. Most food is constituted of about 70 percent water and the specific heat of food can therefore be approximated as 4.18 kJ/kg/^{o}C. If steam is allowed to escape, the required energy to cook 1 kg of meat would be about 936 kJ, whereas with the steam trapped only about 275 kJ would be required. With solar radiation figures of the order of 900 W/m^2, an assumed 20% cooker efficiency and about 150 W useful energy required for a single pot, then the solar collector area required per pot is around 0,98 m^2 (Pinon,1983)

4.6.3. Two Case Studies

<u>KwaZulu</u>

In response to a request from a community agricultural project in KwaZulu, a number of solar cookers, designed by an engineering student at the University of Natal, were build with funds from the Urban Foundation. The cookers were subsequently distributed and their impact assessed in various selected areas in KwaZulu between late 1979 and early 1981. The cooker design and field trial results have been reported by Tully & Lawrence (1980) and Thomas (1984). The cooker design was made as simple as possible to allow manufacture in low-tech rural workshops. The reflective surface of approximately 1.2 m^2 consisted of polished sheet-metal arranged in three concentric cones approximating a parabola. It was mounted on a steel frame with the cooking pot suspended from a hook at the focal point of the reflectors. The cooker was specifically designed for a 5 litre cast-iron pot typically used in rural areas. A diagram of the cooker is shown below.

Figure 4.6.6. University of Natal solar cooker design



In trials at the university, the cooker was found to be able to heat 5 litres of water from ambient temperature to 100°C in one hour on a clear hot summers day. Dry pot temperatures of 150°C were also recorded.

A total of 44 cookers were sold at a subsidised price of R10 each and were distributed in nine communities within the seven bio-climatic zones characterised in KwaZulu. No attempt was made at proportionate distribution within different socio-economic groups, but the sample did include a range of rural and peri-urban communities. Distribution of the cookers was done through existing community organisations in some cases, and on a "drive-in" basis in others. By regular subsequent visits to the users, field workers were able to establish utilisation patterns.

The field trials showed a large variation in utilisation frequency from one household to another, the average being 1 day per week in the range from 4 days per week to one day in 8 months. It was also found that when the cooker was used, it was seldom the sole method of cooking but supplemented a fire or stove.

Calculated energy savings based on the average frequency of use amounted to just less than half a day's fuel per week. The implication of this saving given below are rather disappointing but mask the large variation in use frequency in different households.

- For 91% of the households using wood as their main fuel, the cooker saved 6,4 kg of wood out of an average total of 101 kg wood used per week. This would amount to a saving of 33 kg of wood per household per year.
- The average load of wood carried by women weighed about 40kg, thus the saving is equivalent to a reduction of 8 trips out of a total of 127 collection trips per year.
- Where wood was being bought, the cash saving amounted to about R8-16 per year. This figure covers a range of prices paid for wood in different areas.

Thomas (1984) claims that the solar cookers were not widely used due to poor technical design which gave rise to the following problems:

- Performance on cloudy and windy days was poor, and often the cooker was only set up when clear, windless weather could be guaranteed.
- The large size of the cooker prevented its use by young children who are often put in charge of cooking while their mother is in the fields and older children at school.
- The cooker could obviously not be used for space heating. Open hearth or solid fuel stoves are favoured for cooking because they also serve to heat the house.
- All types of pots could not be used on the cooker, due to the nature of the design.

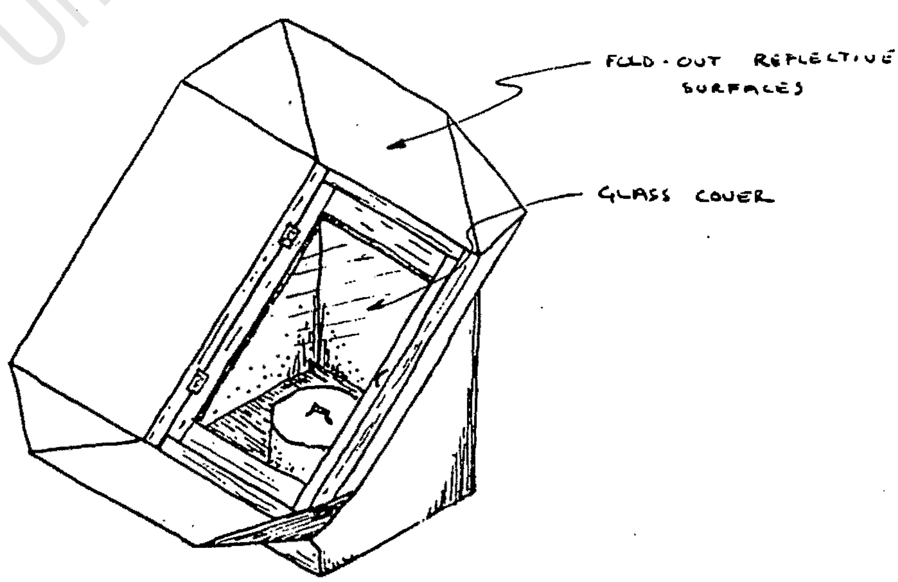
For the area under survey, the household expenditure on fuel as a fraction of income, ranged from an average of 7.9% for the 10 lowest incomes, to an average of 2.6% for the 10 highest incomes. Thomas could find no correlation between solar cooker use and income or expenditure on fuels. The cookers were used (or not used) by low income and high income households alike. There was also no correlation between frequency of use and location in the more favorable climatic zones. The distribution and dissemination was identified as an important factor contributing to utilisation rate. The study showed that where the cookers were distributed through existing community organisations, or by people with a relatively high social status in the community, utilisation rates were high whereas in communities where the cooker was distributed "cold", the utilisation rate was low.

<u>Lesotho</u>

While this is not a South African case study it provides some further information on the problems of introducing new technology into underdeveloped areas. In the mid-70s, a Canadian funded project in the highlands of Lesotho developed among a range of solar devices, a solar oven as an aid to meeting the energy needs of rural households in an area where fuelwood was in short supply. The project was reported in an article by Eberhard (1983).

The oven in question consisted of a double-walled sheet-metal box with the inter-wall space filled with glass-fibre insulation and a double-glazed lid. The interior of the box was painted black and four galvanised sheet-metal plates provided the concentrated supply of solar energy. The oven was found to be able to cook a wide range of foods including porridge, stews, meat and vegetables. Temperatures of 120^{o}C could be maintained on sunny days and the ovens performance was unaffected by wind. The cost of the ovens was the 1981 equivalent of US$45 which put it beyond the means of many poorer households.

Figure 4.6.7. Taba-Tseka solar oven design



After making contact with an outlying village that expressed some enthusiasm for the cookers, 45 ovens were taken by two extension officers to the village and offered free of charge to villagers. The extension workers remained in the village for two months during which time they instructed the villagers on the basic aspects of solar oven use. In this two month period, not all the ovens could be distributed nor were they, with a few exceptions, used frequently by the villagers. When the village was visited another two months later the stoves were being used only occasionally for heating water and when visited seven months later the stoves were hardly being used at all. Follow-up work was subsequently dropped when the research team focussed its attention on the development of fuel-efficient stoves.

The reason why the solar ovens were not readily accepted was attributed not so much to the specific cooker design or technology, but rather to the way in which the project directors approached the domestic fuel problem. As it happened, the development and design of the solar cooker was not a response to a demand expressed by the villagers, but rather the response to a need as perceived by the project managers.

- No surveys of energy usage patterns or demand were undertaken before the start of the oven dissemination project, nor did local residents have any role in originating the project or defining their energy needs.
- Although the organisation was concerned with rural development, funding (from overseas) was limited to "appropriate technology" projects. Choice of the solar ovens by the project managers was to a large extent dictated by the conditions required for aid.
- The direction of the project was to an extent influenced by the self-interest of some aid workers to secure lucrative and renewable contracts.

4.6.4. Solar Cooker Potential

Solar cookers, because of their cheapness and simplicity, could make a considerable contribution towards reducing the dependence on fuelwood in rural areas. However, there are considerable obstacles to be overcome for this technology to be a serious option. Firstly, there is the question of prevailing cooking habits and traditions and to what extent these will be flexible enough to fit in with solar cooker use. Secondly, there are shortcomings inherent in the nature of solar technology such as weather unreliability, the degree of effort and commitment required, and the time taken to prepare a solar cooked meal. Some of these can be overcome by improved design, but some not. The third question is how to create structures for the manufacture and dissemination of solar cookers that will themselves contribute to rural development.

Regarding cooking habits and traditions, the study on energy consumption patterns by Eberhard (1986) provides information from which some useful points can be extracted:

- A high proportion of households do their cooking indoors either because they have existing stoves or because fires are also used for home heating.
- Many of the preferred dishes are porridges and stews which require cooking for an hour or more, which would mean regular refocusing of the solar beam.
- Open fires serve as a focus for family and social activity, a function that a solar cooker clearly cannot replace.
- Most of the cooking takes place in the early morning and evenings which is not suited to a solar cooker. This is particularly the case in areas closer to urban centres where most members of the household are away in the daytime, either at school or at work.
- During seasons of high agricultural activity, midday meals at home may be skipped altogether.

The target market for solar cookers is the very poor who cannot afford commercial fuels in areas where wood is in short supply. Since solar cookers have virtually no running costs, their major cost is initial capital, and to satisfy the target market, this has to be low. Some innovative designs have included locally available natural products such as dried calabashes or gourds, and in other cases oven bodies have been built from mud and wicker-work (Pinon,1983). These cookers are obviously very cheap and could be manufactured on a small scale but do not easily accommodate the cooking requirements listed above. In addition, less sophisticated designs carry a major "inconvenience cost" (in time, effort and commitment) due to the solar cooker's unreliability in bad weather, the effort required to constantly adjust the reflectors and the certain skill required in learning how to use them. Technical innovation may provide designs that overcome these problems and are able to integrate cooking habits and customs, but this is invariably at a higher cost and increased level of complexity.

Strategies for introducing and disseminating solar cookers in rural areas are not fundamentally different from strategies for other "new" technologies. They are perhaps a little more complex because of the cultural status of food preparation, and the sometimes complex traditional roles of family members in a domestic situation. For example, it is often the case that, while women are held responsible for cooking, it is the men that control the household budget. A cheap energy (and money) saving device that may be enthusiastically welcomed by the men may not find favour in the kitchen.

The first requirement for successful dissemination is that solar cookers fulfill a real need in rural areas, and the real challenge at the moment is not to invent new, more appropriate or practical designs, but to determine under what social or cultural conditions solar cookers will find acceptance.

4.7. Hotboxes

4.7.1. Introduction

Another appliance for increasing the efficiency of the cooking process is the hotbox, also known as the haybox or wonderbox. In principle it is merely a well insulated box into which a pot of heated or semi-cooked food is placed. The cooking process is then completed without further energy input. While the food invariably takes longer to cook, the lack of excessive or vigourous boiling allows more of the original nutritional value of the food to be retained. It has been found that, while use of the hotbox does save energy, the primary motive for it's purchase is often because of it's convenience.

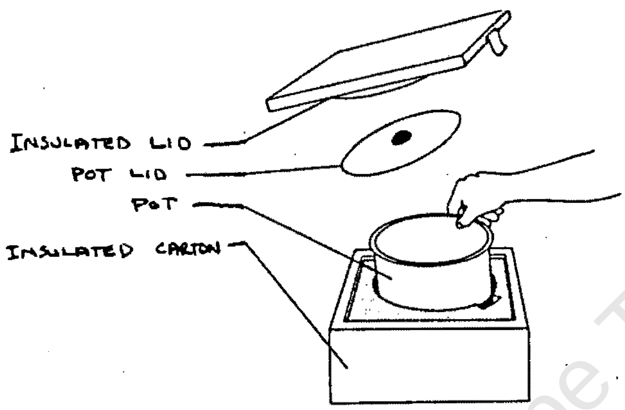
The hotbox is possibly the cheapest and most simple of all the technologies reviewed here, which is in many ways its greatest advantage. Because of it's simplicity, it is well suited to local small-scale manufacture and distribution. In fact until now, the manufacture and distribution of hotboxes in South Africa has been mostly through the agency of self-help employment schemes, church groups, charitable organisations and the like.

4.7.2. Hotbox Technology

In principle, the hotbox is nothing more than an efficient insulator. The term hotbox, covers any device which, once the food has been brought to the boil and removed from the heat source, encloses the pot in an insulating material thereby reducing the rate of cooling. The hotbox can be used in this way both for cooking food, or simply for keeping it warm while the stove or fire is used for another purpose. An obvious disadvantage of the hotbox is the length of time it takes before the food is thoroughly cooked. Effective use can be made of the hotbox if food is partially cooked in the morning and left in the hotbox through the day to be eaten at night, similarly for food prepared in the evening and left overnight. It is also highly suitable for dishes requiring long simmering periods.

The construction of a hotbox can vary enormously, depending on the creativity of the designer. A typical design of "wonderbox" is shown in the figure below.

Figure 4.7.1. A typical "Wonderbox"



Designs of hotbox have included a hole in the ground lined with hay, cardboard cartons stuffed with rolled up pages of newspaper, or waste polystyrene chips enclosed in two or more fabric bags. In fact almost any container filled with almost any form of insulator will work to some degree. The principle of hotbox cooking is not new and its simplicity leaves little room for significant technological improvements. Improved performance can be obtained with better insulators, but at greater cost.

4.7.3. A Case Study

There have been two major surveys conducted to asses the impact of hotboxes as an energy saving technology. The Department of Development Aid analysed 296 questionnaires received from various government agricultural and health stations throughout the country, but the quality of the survey was poor and difficult to draw conclusions from. A more thorough survey was undertaken for the National Energy Council by Gandar & Udit (1988). For a number of years prior to the study, "wonderboxes" had been distributed in the Natal area by charities, non-profit, and self-help organisations. The survey's objective was to determine if the technology was having sufficient impact on nutrition or the energy economy of rural and peri-urban communities in the area. Although the survey was confined to the environs surrounding Durban and Pietermaritzburg, the results can be extrapolated to other rural locations.

The major part of the survey was done on a door-to-door basis covering a sample size of 125 households, approximately half being wonderbox owners. The major distributors were contacted and interviewed and supplied with questionnaires for future buyers. Some of the salient points brought out by the study are summarised below:

- The majority of wonderboxes are bought by whites although the majority of users are black. About half of the wonderboxes bought by whites were intended as gifts for their black domestic workers.
- Of the black users and buyers, the majority (64%) were in waged employment, and the wonderboxes were found as frequently in rural households as in peri-urban households. Of the non-users, only 24% were employed.
- The majority of wonderbox users cooked on primus stoves, while households without wonderboxes cooked mostly on open wood fires, indicating a higher level of sophistication among the users.
- Among household without wonderboxes, the general level of awareness of the technology was low. Sixty-four percent had never heard of them, while those who had, did not know how they worked or what their advantages were.
- Of those who owned wonderboxes, the majority had heard about them from the distributors (51%), followed by friends and relatives (28%) and employers (21%).
- Among users, energy or fuel saving was the most frequently mentioned benefit of the wonderbox but for first-time buyers the main perceived benefit was in the time it saved and its convenience. Energy saving came as a secondary but important consideration. This could be an important factor in a future marketing strategy which so far, has been centred around the energy saving benefit.
- An additional benefit cited was that the use of the wonderbox did not require a radical change in traditional eating habits or diet.

About half of the owners claimed to be using the wonderbox daily and 94% were using them at least twice a week. Owners estimated that their average weekly paraffin consumption fell from 11,6 litres per week to 5,6 litres per week on acquisition of a wonderbox. A calculation, based on an average usage of four times a week, gave an average fuel saving of 1,1 litres of paraffin per week per household. This agrees well with the figure of 1,4 litres/week obtained by an earlier survey (Dept of Development Aid,1986). Most respondents in the survey thought that the wonderbox had paid for itself in fuel savings.

The use of a wonderbox was in some cases responsible for a change in diet (most boxes come with a recipe book) or for a shift in fuel use from wood or coal to paraffin. The wonderbox allowed flexible cooking patterns although they were most frequently used for food cooked in the early morning.

Regarding design, most owners felt that the boxes could be made stronger. Some also wanted larger boxes or to be able to replace certain parts of the wonderbox without having to buy a complete unit. The aesthetic appearance was also felt to be important as long as this did not affect the price too much.

4.7.4. The Potential for Hotboxes

Where the distribution of hotboxes has been sufficiently concentrated, it appears that they have been well received. There is also evidence that fuel savings have been obtained by regular users. As a serious solution to fuel shortages, it is of course necessary that the device be correctly and regularly used. There may also be limitations in that certain dishes cannot be cooked in this way

At present, hotboxes are sold or donated mostly through charitable or self-help organisations or are made by the users themselves. The survey by Gandar & Udit (1988) outlined above, showed that most hotbox owners had acquired them from their white employers, and while there seemed to be a ready market for the boxes, they were not available through the established network of wholesale and retail shops serving rural areas.

Given a basic understanding of how insulators work, the hotbox can be home-made at "zero-cost" from materials that would otherwise have been thrown away. Commercially, hotboxes have been manufactured on a small-scale by numerous self-help groups and charity organisations. In most cases, prices have been kept low through using waste materials and their own cheap labour but these organisations have not had the marketing infra-structure to reach a wide market. Commercial retail stores do not stock hotboxes because there is no reliable supply, and there is no incentive to manufacture on a consistent scale because there is no convenient retail outlet.

Gandar & Udit (1988) suggest that the wider distribution of hotboxes requires the intervention of an outside agency. The function of the agency would be to co-ordinate the development of a large-scale manufacturing centre simultaneously with the development of commercial distribution and advertising. Alternatively the agency could assist small-scale manufacturing concerns with the buying of raw materials, and marketing. It would seem that there is room for a more concerted effort in disseminating this simple but effective technology in rural areas.

4.8. Solar Water Heating

4.8.1. Introduction

The amount of fuel used for heating water, whether for personal hygiene, washing, laundering or cooking, contributes significantly to the total fuel consumption of rural households. There is very little information on hot water consumption patterns in rural areas, and hot water needs are difficult to gauge since, in many rural areas, consumption is constrained by the availability of fuel and water. Solar water heating (SWH) technology has been well established in the developed urban sector, and if it can successfully be implemented as a fuel alternative together with improved water supplies, it can reduce fuel consumption and increase general living standards.

The standard commercially available SWH units are beyond the means of most rural households, although there does seem to be a trend towards producing cheaper units. Most commercial units are also generally designed for use in houses with piped water supply, a service not common in rural areas except perhaps in some communal centres, schools and hospitals. Considering the unsuitability of commercial-type solar water heaters for rural situations, this section will deal with what are essentially "no-cost" solar water heaters. The principle of solar water heating is relatively simple and is a technology well suited to construction with simple tools from cheap, locally available materials.

4.8.2. Hot Water Consumption in Rural Households

There is not much information on hot water consumption by rural households. As a comparison, a study of low-income black households in two townships on the Highveld gave a hot water consumption for non-electrified households using solar water heaters as just over 99 l/household/day, extrapolated to about 17.5 l/person/day (McLean et.al.,1985:5). The households had piped water but no electricity. Rural households without electricity or piped water are likely to consume much less than this.

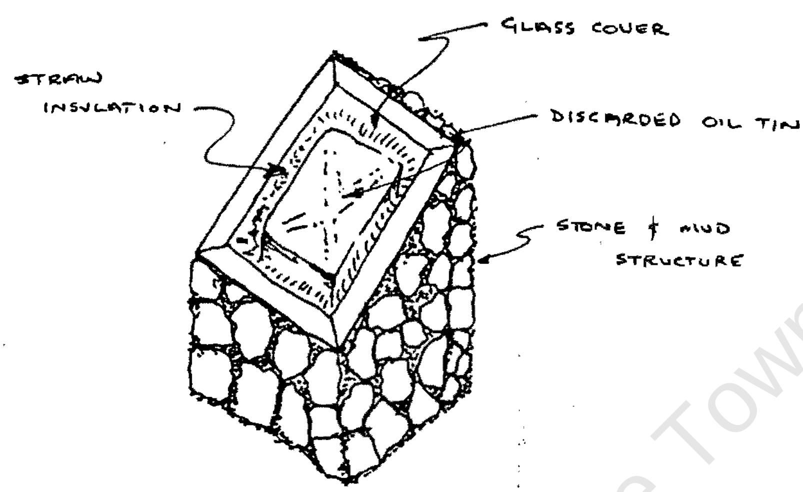
Hot water comsumption can also be gauged from <u>total</u> water consumption patterns in rural areas which range from 10.88 litres/person/day (Friedman,1984) to about 15 litres/person/day (Eberhard,1986) to 75 litres/household/day (Stone,1984). One of the studies (Eberhard,1986) found that of the total water consumption, about 30% was used for cooking, 15% for drinking, 15% for washing dishes and about 40% for bathing. If it is presumed that all the water for washing and bathing, and half the water used for cooking needs to be heated, then the hot water consumption is 70% of the total water consumption.

Because SWH systems are dependent on sunshine, the performance of a system is affected by when the hot water is required. Klein and Wyatt (1978) working in Lesotho, showed that rural households in their study area required most of their hot water in the mornings for personal hygiene and lesser amounts through the day for cooking and dish-washing. The high early morning consumption was also noticed in urban areas (McLean et.al.,1985:5), and unfortunately does not favour solar water heaters. They also found that in the early mornings, water was usually heated on a paraffin stove if the fire was not already lit, and for water used later in the day or after a meal, a tin was kept next to the fire to warm up.

4.8.3. Solar Water Heater Technology

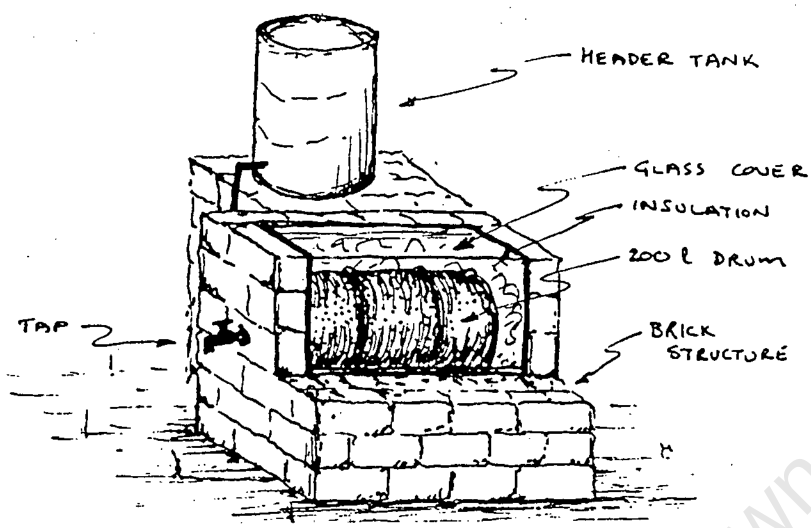
A typical low-cost batch SWH described by Klein and Wyatt (1978) is a portable, water filled container preferably with a large blackened surface, which is placed in the sun. Performance can be improved by placing the container inside some sort of structure covered by glass or clear plastic to allow in the sun's rays but trap the heat and shelter the container from the cooling effects of the wind. Insulation can be used to prevent heat loss from surfaces not exposed to the sun. When the water is hot enough, the whole container is removed from the frame and replaced with a new batch of cold water. This is an example of a device that can be with the minimum of skill using readily available materials.

Figure 4.8.1. A Typical Low-Cost Batch Solar Water Heater



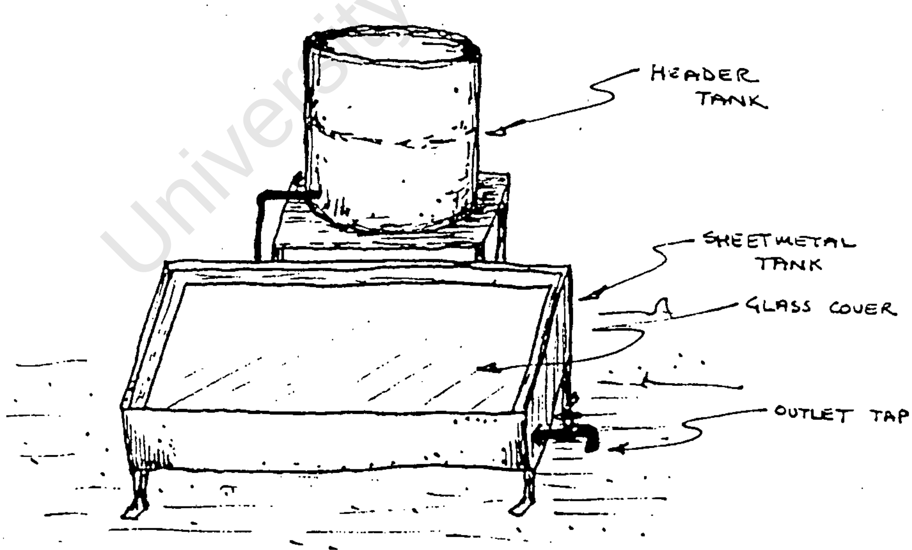
A slightly more complex flow-through SWH for households without piped water has been developed by the Rural Industries Innovation Centre (RIIC) in Botswana. This consists of a header tank connected to the solar collector which is painted black and mounted inside a glass covered case. The collector has an outlet tap. While exposed to the sun, the water inside the collector tank warms up and when required, warm water is drawn out of the tank. The header tank, placed above the collector tank, ensures that cold water is automatically replaced by gravity pressure. All that is required is a periodic refilling of the header tank with cold water. There are two designs offered by RIIC operating essentially in the same way, but constructed is slightly differently. The "brick" model is a permanent structure with the collector tank (a converted oil drum) housed inside cement block walls and a glass roof. A packing of glass-wool or straw is placed around the unexposed areas of the tank and the exposed area painted black. It is available in 100 and 200 litre capacity. It can be made on site and does not require too much skill to build

Figure 4.8.2. The RIIC Brick Solar Water Heater



The "blacksmith" model has the solar collector assembly fabricated from sheet metal, insulated with glass-wool and covered with a glass top. The unit can be mounted on a stand and is easily portable. It has a capacity of 65 litres. The construction of this model requires some skill in metalwork and was developed to encourage the commercial manufacture of these units at small rural workshops.

Figure 4.8.3. The RIIC Blacksmith Solar Water Heater

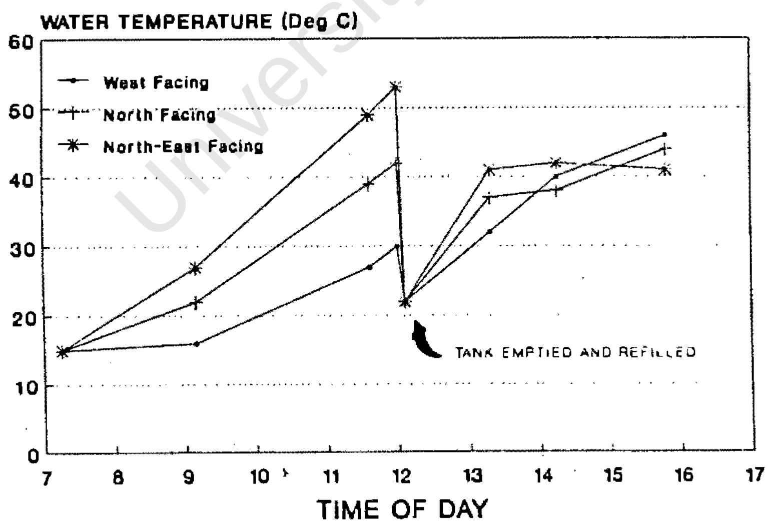


4.8.4. A Lesotho Case Study

Klein and Wyatt (1978) in a Canadian funded rural development project in Thaba Tseka, Lesotho, developed and tested various designs of low-cost batch solar water heaters which could be easily made from cheap, locally available materials. An ideal basis for the heater was the commonly used five litre cooking oil cans. Once the oil was used up, these cans were used for carrying water and for heating it by the fire. For the project, these cans were blackened with soot, filled with cold water and then placed in simply constructed frames and allowed to warm up in the sun. Figure 4.8.1. shows the type of heater developed here.

Different frame designs were tested using a variety of locally available materials to determine costs and performance. One of the most simple designs consisted of a frame made of mud or stones and insulated with straw. This was shown to work well enough to be practical. On a sunny day, usually two batches of water, warm enough for personal use were obtained in this manner. A graph of time versus temperature for one of these heaters is shown below.

Figure 4.8.4. Batch Heater Performance



Several different models were built, tested and demonstrated at the project's headquarters. It is not known whether any of these designs were actively disseminated or what impact they had on rural people in the area.

4.8.5. The Potential for Solar Water Heaters

Because of it's inherent technical simplicity, solar water heating is well suited to dissemination along the lines of classical "intermediate technology" philosophy. In other words, there is scope for the development of an effective yet simple design which could be user-made or manufactured in small workshops and which would create employment oportunities while filling a real need in rural areas.

As estimated above, the consumption of hot water in rural households is around 70% of the total water consumption, which reduces to a figure of around 10 l/person/d. If this water is required at say $55^{\circ}C$, it represents a "useful" energy requirement of 27% of the total requirement as estimated in the discussion in Chapter Two. If a solar water heater could provide half this amount of hot water it would contribute to a substantial saving of fuel.

A solar water heater can save fuel but only at the cost of some inconvenience, and the more simple the system, the more the bother. Simple units have to be constantly kept full, positioned in the right direction, will only work well when the weather is sunny, and will not provide warm water in the early morning. Obviously then, where there is not incentive to save fuel, there would be little inclination for rural households to invest time and effort let alone money on such an appliance. Target areas for such appliances would be areas where households are heavily dependent on particularly expensive commercial fuels.

The introduction and dissemination of solar water heating devices could take three possible routes. Firstly, rural households could be made aware, through educational programmes and extension work, of the principles of solar water heating and fuel savings to be obtained from simple, cheap, home-made devices. Secondly, the design of a simply-made but more sophisticated, efficient system could be promoted with the aim of creating a manufacturing industry for rural workshops. Thirdly, a mass-produced, relatively cheap system could be sold through existing rural retail outlets.

4.9. Energy Efficient Housing

4.9.1. Introduction

One of the major uses of fuel besides cooking and water heating is space heating. The object of increasing the thermal performance of rural dwellings is therefore to reduce the fuel requirement for space heating, thus reducing overall fuel consumption.

Rural homes are built by their owners, informal contractors, by community group cooperation, or a mix of the above. Without superficially imposed constraints, rural house designs tend to be a dynamic response to a combination of cultural factors such as defence, family unit size, wealth, dominant agricultural practice and tradition, and and environmental forces such as climate, geography, water availability and proximity of arable land. An additional important force in recent times has been the influence of Western ideas and modern building materials and the rapid change in the primary function of rural dwellings from farming homesteads to home-bases for migrant workers.

In assessing the role that passive solar design can play in improving the level of thermal comfort, it is of interest to look at the role of passive solar design in existing building traditions, the thermal consequences of the use of "non-traditional" building materials and changing building practices, and how passive solar design principles can be incorporated into both "traditional" and more "modern" rural dwellings.

4.9.2. Thermal Considerations in Traditional Dwellings

It is important, when offering possible improvements to the thermal design of rural dwellings, to acknowledge the extent to which traditional designs already compensate for climatic conditions. It is also important to acknowledge that there are other factors besides thermal comfort that influence where people live and the way they build.

Archaeological investigations (Wilson & Thompson,1982) show evidence of large rural settlements in South Africa dating back to before the tenth century A.D. With a tradition this old, it is not surprising that many traditional dwellings today include elements of sensible passive solar design. An astute observer travelling overland from the Transvaal highveld to the Natal coast will notice in "traditional" rural dwellings, the progressive reduction in building mass, from thick mud walled huts to grass-only structures, as the decreasing altitude invokes a milder, less extreme climate.

Sensitivity to environmental factors play a strong part in the siting of huts in mountainous areas of Lesotho. A study by Fuggle (1971) found that the highest distribution of huts occurred in a altitude band on the upper slopes of the hills, well away from the effects of severe temperature inversions that occurred in the valleys at night. Dwellings were also almost exclusively confined to north-facing slopes for maximum sunshine. Prior to this study, researchers had tended to accept that the dominant factor in the selection of a dwelling site was the Basotho's need for an easily defensible position.

In another study of traditional housing and environment, Siegfried and Hough (1986) working in the Transkei found a positive correlation between hut orientation and wall ornamentation on the one hand, and distance from the coast on the other. They proposed that, in dwellings near the coast where the climate was mild, orientation was not an important consideration. However the orientation of houses inland was almost always north-facing, due to the more severe climatic conditions in the high-lying areas. They also found that in the colder inland areas, hut ornamentation was confined to two main types, characterised by the large areas of unpainted, dark brown wall surface which could best absorb the daytime solar radiation. Huts nearer the coast displayed a large variety of wall ornamentation, including designs with large white painted surfaces, indicating no practical function.

4.9.3. Improving Rural Homes

To help people get the maximum thermal benefit out of their neo-traditional concrete block and corrugated iron houses, the Ministry of Cooperatives and Rural Development in Lesotho (AT Unit), in a project jointly sponsored by the Lesotho

Government and USAID, produced plans and pamphlets showing ways of improving the thermal performance of standard concrete block and corrugated iron buildings. Modifications are fairly simple and include correct north orientation, bigger north-facing windows, draught exclusion and ceiling insulation (RETP,1982a). Similar pamphlets have been prepared to make builders of traditional-style stone & thatch houses more aware of energy saving designs. Suggestions include adding a wind sheltered porch, increasing north-facing glazing, draught exclusion and the effective use of curtaining (RETP,1982b).

The Transkei Appropriate Technology Unit (TATU), some years ago, attempted to influence the design of buildings in the Transkei. A number of community halls, schools and other buildings were built by TATU in various villages to demonstrate the advantages of energy efficient design while retaining the best features of "traditional" styles, and using locally available materials as far as possible. Their recommendations however, were invariably rejected by Transkeian authorities in favour of high-cost, "modern" designs from "across the border". These decisions were no doubt influenced by vested interests of the politicians, contractors and other professionals who stood to gain from expensive constructions, but also attest to apparent "...culture war being fought out by the Black and White elites of southern Africa..." (Cook,1988). The result has led to a situation where the embracing of antiquated, inefficient European architecture is seen by the rural population as being a more desirable cultural route than the development of an appropriate vernacular-based architecture.

4.9.4. Some Passive Solar Design Solutions

The elements of passive solar design that are most effective are also the most simple. North-facing orientation, roof overhangs, wall mass and ventilation control may not add appreciably to the cost of a new house, yet they can make that house considerably more comfortable to live in and reduce the amount of fuel required for space heating. While traditional builders may not think of house design in these terms, it is evident that thermal comfort has influenced the design of "traditional" dwellings in South Africa. In many respects, the evolution of traditional rural designs and building skills has been interrupted by the rapid social transformations characteristic of many rural "homeland" areas. This disruption has been accompanied by the substitution of traditional building materials with more durable modern building materials such as concrete blocks and corrugated iron. The new materials have different, often poorer, thermal properties and while the materials are easily imported into rural areas, the skills and craft appropriate to those materials are not. The mastery and skill that has guided rural building traditions may not be able to survive the transition to new dwelling requirements, styles and materials. The question is how these traditions can be retained into the future and how can they be improved with newer ideas.

Traditional building practices are also being forced to change due to an increasing scarcity of traditional materials. The shortage of wood in many "homeland" areas has most vividly been described as a fuel problem but it has also caused a shortage of wood poles used for building. A Basotho practice of building rondawels with double walls separated by a framework of thermally insulating reeds is now seldom used, ironically because the reeds are regarded more valuable as firewood (Norris,1982:17).

The promotion of passive solar designs for traditional housing in rural areas is equivalent to creating a "new" science out of something that has been applied for generations. Unfortunately, with modern urban influences increasing, the application of traditional passive solar techniques is being replaced in favour of whatever looks modern, wealthy or looks like it belongs in a city. For passive solar design to be widely accepted, dwellings incorporating the ideas of passive solar design need to be shown to be undeniably superior to European-type housing; popular only because it represents a cultural leap in the minds of rural people.

4.10. Photovoltaics

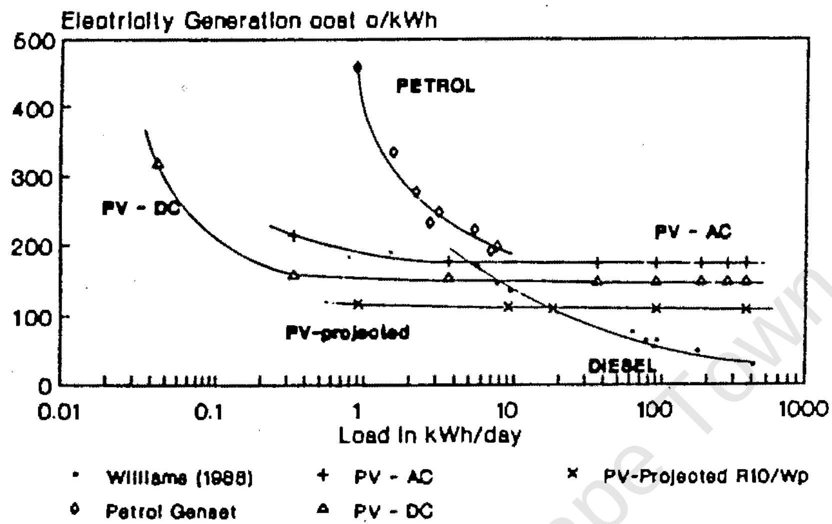
4.10.1. Introduction

The benefits of rural electrification are discussed in full in the next section (4.11) on grid supply to rural areas. The advantages of having a power supply for electric lighting, radio and television are in any case, self evident. Before discussing grid electrification, it is worth while looking at the potential role of photovoltaics in providing low-power electricity supply to rural households. There are a number of reasons why photovoltaic (PV) systems should be considered in rural areas:-

- If a national electrification programme was implemented, it would very likely concentrate on urban areas, and it would be many years before all rural areas were electrified. Until then electricity demand would have to be satisfied with costly alternatives such as car batteries and small generators.
- Experience has shown that the demand from new low-income consumers is almost always confined initially to low-power applications such a lighting, radio and television. Photovoltaics are ideally suited to low-power applications.
- Photovoltaics deliver power at a low voltage and are thus an attractive alternative where house construction standards may make 220 V wiring difficult and dangerous. Photovoltaic systems are portable, and in areas where tenure is uncertain, a household forced to move can take it's power system with it.
- Photovoltaic systems are clean, require little maintenance and make use of a renewable energy source.

The most important low-power electricity application demanded by households is lighting. Although candles and paraffin lamps are used, they do not match the quality or safety of electric lighting. Where electrical appliances such as lights, radios and televisions are used, they are usually run off car batteries or small generators. Car batteries are an extremely expensive source of energy and are particularly unsuitable for home power supply. Generators are also expensive to run and maintain in remote areas. In comparison with small petrol generators (1 to 5 kW), power from a PV system is almost always cheaper. With loads of above 10 - 20 kWh/day, diesel generators become more competitive than both PVs and petrol generators.

Figure 4.10.1. A Cost Comparison of PV vs Petrol Generator



Source: Borchers (1989)

Although the use of PVs for home power in South Africa is at present limited to a small number of applications, it has been used successfully in a number of pilot schemes for village electrification in Tunisia, Gabon, Egypt, Senegal and Burkina Fasso (Sinclair,1989:102). In Spain, one of the fastest growing PV markets in the world, some 24 000 houses in the Andalucia region and Baleares Islands have PV installations to supply electricity mainly for lighting, television sets and radios (Eberhard,1986:11). The demand for low-power electrical supply has stimulated a growing market in South Africa, and it is now possible to buy pre-assembled "off-the-shelf" PV systems specifically for home lighting, consisting typically of a solar panel, battery, control box, wiring and a number of flourescent lamps. These systems are pre-wired and can be installed by the homeowner with the minimum of skill required. The technical details of photovoltaic systems, and an economic evaluation have been discussed in detail in Section 3.3. on photovoltaics in urban areas. The points made there hold equally well for rural areas and will not be repeated.

4.10.2. Omdraaisvlei: A Case Study

A PV system was installed by the Energy Research Institute, University of CApe Town, in a labourers three-bedroom cottage on the farm Omdraaisvlei in the Upper Karoo near Prieska. The system was monitored over the period of a year (Muller,1988 and Sinclair,1989). The installed system consisted of:-

- Two M-Setek MSP-103, 41 Wp modules.
- One 98 Ah Sabat battery.
- One Arco Solar battery protector rated at 20 amp.
- Four 20 W lights and two 11 W lights and a socket for a portable TV set.

The load was estimated at 366 Wh/day based on the assumption of 3 hours/day of lighting and 4 hours/day of TV watching. The panels sizing and optimum tilt angle calculation was based on solar radiation data for Bloemfontein for the "worst month" (21,7 MJ/m^2). The tilt angle was set at 35^o. This gave a projected output of 91 Wp with a battery storage requirement of 95 Ah.

Actual solar radiation measured at the site after installation was only 2,5% higher than the design figures used, but the load was seriously over-estimated. Actual power drawn was only 115 Wh/d, a third of the design load. This was explained in part by the frugal habits of a family unused to a "free" source of power.

After about one years operation, a fault in the regulator caused the system to fail. It remained out of service for a considerable period of time due to the inability of the householders or the farmer to diagnose and correct the problem.

The case study highlights the importance of correctly sizing the unit, based in turn on the ability to correctly estimate the load. In this case study, the actual load drawn was only one-third of the design load. The cost implications of overdesign are well illustrated in Figure 3.3.4. in the section on photovoltaics in urban areas. The study also highlights the problems of maintaining a "high-tech" appliance in a remote rural area, where residents do not have access to service depots or spare parts.

4.10.3. Photovoltaic Potential

The use of candles and paraffin for home lighting, and batteries for electricity supply indicates a demand for electricity supply, which could be ideally met by photovoltaic systems. PV systems are already fast gaining popularity in remote areas as stand-alone power supplies, and in many cases are cheaper than diesel, petrol or grid extension. At current prices however, PV systems for household use are only available to the relatively well off. While prices remain high, the penetration of PV systems into rural areas will most likely be limited to communal centres such as schools, clinics and hospitals.

4.11. Grid Electrification

4.11.1. Introduction

To provide each and every rural household in South Africa from a national grid would be an enormous and expensive task. Even if the finance could be made immediately available, the sheer scale of the undertaking would mean many years before the project is completed. It would also be a number of years after this that rural households could afford to start buying the necessary electrical appliances to make full use of the electricity. As such, grid electrification cannot be considered an <u>immediate</u> solution to household energy problems in rural areas. On the other hand, technologies such as fuel-efficient stoves, woodlots and the like, important as they may be, cannot be more than temporary solutions to the increasing energy need, the desire for development and the demand for higher standards of living.

While this chapter is primarily concerned with energy technologies for household requirements, it will become clear in the following sections that rural electrification cannot be justified only on these grounds alone. Household supply must be seen as one part of an overall electrification scheme which would include rural commercial and industrial facilities. Argument for a rural electrification scheme would thus include benefits from the stimulation of rural agriculture, commerce and industry, and the consequential economic, political and social upliftment. In this regard it is worth mentioning again, the lack of separation between domestic and industrial activity in rural households. While in urban areas, the home and the workplace are often separate and energy in the home is generally for "unproductive" applications, this is less so in rural areas, particularly where families are working small agricultural plots for profit or subsistence.

Rural electrification is perhaps the most exciting of the options for rural households. While complete electrification of all rural areas in the country would be an ambitious and expensive undertaking, there are a number of areas where, depending on costing philosophy and grid extension distance, electrification is cheaper than other comparative options. The following section will attempt to put the issue of rural electrification in South Africa into perspective by outlining the present situation, discussing some of the perceived benefits of rural electrification, some technical problems that need to be faced and the costs involved in such an undertaking.

4.11.2. The Present State of Rural Electrification

Although it is difficult to determine the exact number of households that would qualify for a rural electrification scheme, Dingley (1990:10) has estimated that 4 million households country-wide are without access to electricity. It can be assumed that roughly half of this figure, 2 million, are households in rural areas, defined in this case as those areas where electrification would require substantial extensions to the existing national grid network.

Before going further, it is useful to compare rural electrification in South Africa with some other developing countries:

Table 4.11.1. Rural Electrification in Some Developing Countries in 1983

COUNTRY	GNP/CAP 1983 (US$)	APPROX. POPULATION (millions)	PERCENT OF RURAL ELECTRIFED
Syria	1760	10	20
Turkey	1240	47	50
South Africa*	**1221**	**32**	**10#**
Costa Rica	1020	2	95
Thiland	820	50	40
Phillipines	760	52	22
Ivory Coast	710	9	20
Egypt	700	45	23
Senegal	440	6	12
Pakistan	390	90	15
China	300	1019	30
India	260	733	15

* figures are for 1985
# estimate by Dingley (1988:5)

Source: Munasinghe in Dingley (1988a:4)

The figures above indicate how far advanced rural electrification programmes are in many countries less well off than South Africa. Bear in mind however, that the figures say nothing about the "quality" of supply - voltage fluctuations, reliability and limitations on load. The definition of "rural" may also differ from one country to the next. Nevertheless South Africa with all its wealth and technical know-how does not compare well, particularly when considering that many rural areas are well served by a grid infrastructure, but its benefits are available to "white" farms only.

Since the introduction of electricity in South Africa in the late 1900s, there has been no attempt at bringing electricity to underdeveloped rural areas. Rural electrification as such, has been confined almost exclusively to a small number of white-owned farms. Figures released by Eskom stated that they were to allocate R 25 million in 1986 to increase the number of rural consumers from 7 500 to 8 400 (R 28 000 per new consumer) (SAIRR,1987a:11). The 1987 Eskom rural electrification budget allocation was some R 300 million, of which ninety-nine percent was to be spent on supplying about 9 000 white-owned farms (about R33 000 per farm) (SAIRR,1987b:13).

In recent years, Eskom has increased the power supplied to "independent homelands" by 33 percent, but in 1987 this amounted to a mere 294 GW out of a total Eskom supply of 10 600 GW (SAIRR,1987b:13).

The reasons given by officials as to why so little is spent on rural electrification in black areas are among others, that:

- local authorities are not always in the position to supply the infrastructure required for electrification;
- dwellings are scattered, increasing the costs, and the difficulty of supply; and
- the technology for wiring of traditional rural houses to an acceptable standard has not yet been developed.

While some of these reasons may be partly valid, it is also true that since the creation of "homelands", the development of these areas has never been very high on the governments agenda. It is only very recently that the importance of including these areas in a national energy policy has been realised.

4.11.3. Rural Electrification Technology

Many developing countries embarking on rural electrification projects do not have the technical capability to build the extra power stations or install the long distance power lines that may be required for a rural electrification programme, and have to import this at great cost. This is less of a problem in South Africa, where Eskom is considered a world leader in some fields of power generation and high-voltage transmission. However, most of the expertise has been concentrated on supply to industrial or urban consumers where "first-world" standards have been applied. One of the big technological challenges with rural electrification, is how to safely provide electricity to dwellings that do not conform to "western" building standards and how to organise metering and billing systems in remote, though highly populated areas without an urban-type infra-structure. Another technological challenge is how to reduce the costs of setting up and maintaining the vast distribution network required. This is particularly important given that the costs of rural electrification would have to be largely subsidised.

With regard to supplying rural homes with electricity, much of the technology presently being developed for low-income urban housing could be used with little modification. The pre-payment meter and pole-mounted "Redi-Board" (a combination fuse-box and plug outlet) for example, is ideally suited to the rural situation. These have been discussed in more detail in Chapter 3 in the section on urban electrification.

Distribution system technology has in the past been based on standards developed for urban areas. Costs could be substantially reduced by using standards more appropriate to rural areas. Some points are listed below:

- Single-phase supply is cheaper than conventional 3-phase by approximately half, and is in most cases, adequate for rural supply. However, it is limited to loads of below about 50 kVA.
- Single-wire, earth-return sytems, where possible, can reduce costs substantially. An earth return means that the distribution system needs less conducting material. Lines are lighter and cheaper supporting structures can be used, or poles can be spaced further apart.
- Distribution system over-design, so as to reduce the future costs of upgrading, should be avoided. By keeping initial costs as low as possible, the service can be

extended to as many households as possible. The benefits of electrification can be more widespread, increasing the development impact on rural areas, and increasing the ability of rural communities to contribute towards future upgrading costs.

With a good modern technological base, and a high rate of unemployment in rural areas, consideration can be given to alternative labour-intensive methods of electrical infrastructure development. The setting up of high and medium voltage lines in rural areas would require many new roads to be built, a multitude of holes to be sunk and poles to be raised. Much of this could be done by manual labour recruited from surrounding areas. The subsequent routine maintenance of the system could also draw on local manpower and local materials.

4.11.4. The Impact of Rural Electrification

The immediately recognisable benefits of domestic electrification are largely self-evident. No-one who has had the opportunity of using electricity and electrical appliances in the home would seriously contemplate a return to wood fires and candles. The longer-term benefits, however, are difficult to quantify, and the causality relationship between rural electrification and development can only be left to informed speculation.

Researchers studying rural electrification schemes have identified a number of factors which rural electrification has, or is claimed to have, an impact on. Many of these relate to electricity supplied to rural industry and commerce, community centres and schools, rather than electricity supplied to individual households. Since the two are likely to occur simultaneously, the whole range of benefits and effects will be discussed. Most of the information discussed below is derived from an International Labour Office publication (Fluitman,1983) reviewing electrification projects in other Third World countries. Unless otherwise indicated, all page numbers refer to this publication. These general observations on rural electrification have been collected from programmes in a number of countries with very different economic and political structures, and should not be directly extrapolated to South African conditions.

Incomes and Poverty Alleviation

There is generally a strong and positive correlation between electricity use and household income. However, this is because better-off households are first to use electricity not because the supply of electricity increases income. On the available evidence, electrification tends to accentuate disparities in income rather than alleviate them. Those who can afford the initial connection tend to benefit to the exclusion of low-income groups. However, USAID surveys in Ecuador showed that people were prepared to go into substantial debt to obtain electricity. The same trend has been observed in other countries (p43). While electricity itself does not directly meet a basic human need nor help the poor, it can be an important element in a rural development programme which may help the poor if that programme itself is directed towards helping the poor.

One way of giving the very poor access to electricity is to introduce connection fee subsidies. However, this does not always have the desired effect, since the number of households connected bears no relation to electricity consumption and, if low-income households cannot afford the initial cost of a hook-up, their income is likely to limit their subsequent demand. Considering the low consumption of poor households, their personal savings due to electricity use would be marginal, while the desperately poor would not be able to afford electricity at all. An exeption to this argument is the experience in Bolivia, where the level of saving achieved in rural households added a noticeable impetus to commercial activity in rural centres, with indirect benefits to the poor in terms of increased income, employment opportunities and social services. Of this rural electrification programme, a USAID report said: "One might describe the entire effort as a classic attempt at 'trickle-down' economics and, horror of horrors, it worked (p47)".

Agricultural Production

There is seldom evidence that mere electrification automatically leads to higher agricultural output. There are factors such as soil fertility, climate and land tenure systems which may put a ceiling on agricultural production, but where this is not the case, possibly the primary potential benefit of rural electrification to agriculture is in increased control over water supplies (Cowan,1986:6). This is particularly significant for most of rural South Africa where rainfall is often a limiting factor in agriculture, and where irrigation is often done by laborious and time consuming manual methods.

Agricultural processing can benefit from electrification. A study in Costa Rica found that milking, refrigeration, heating and water pumping, were activities greatly enhanced by the availability of electricity. Electricity also allowed the decentralisation of crop processing centres, saving farmers time and effort, and allowed the use of power-tools for maintenance and repair of farming implements. All these factors were cited by farmers as contributing towards higher agricultural productivity (p35). The benefits however, depend not only on the availability of electricity, but also on the quality of power supply and the extent to which the local infrastructure allows farmers to purchase electrical machinery or to service and maintain their existing equipment.

<u>Rural Industry and Commerce</u>

The biggest growth potential for rural industry is in agricultural processing, as discussed above, or from producing goods that use agricultural products as their raw materials. The effect of electricity however, depends primarily on whether the agricultural output is high enough to demand mechanisation and is not limited by some other factor such as lack of capital or poor infrastructure.

Rural industry in China and Costa Rica have benefited greatly from electrification. But in these countries, it was accompanied by a political commitment to develop rural areas and to establish the necessary technical and commercial infrastructures to support rural industry (p35). In Bolivia and the Philippines, rural electrification projects had no effect on the development of rural industry. This was attributed to the lack of accompanying services and development capital (p36).

Electrification invariably changes the nature of labour practice and employment. If it is accepted that electrification plays a key role in industrialisation, then it could be the cause of more jobs. It is also true that, as a labour-saving technology, it can create unemployment. In China, labour savings as a result of electrification allowed the freeing of workers from strictly agricultural tasks and their absorption into labour-intensive rural infrastructure projects and other small-scale industries. Rural women who are bound to domestic activities may also be freer to find gainful employment with the help of labour-saving household electrical appliances.

In some cases, electrical power has merely replaced activities previously performed manually by individual households or cottage industries. Electrification has allowed them to become "industrial" which does not necessarily mean and increase in productivity or efficiency. The industrialisation of cottage industry has also had the effect of changing the composition of the work force, young having taken over from old, men from women and literate from those without formal training (p41). Nonetheless there are many types of cottage industries that would benefit from electricity.

Health, Welfare and Education.

Electrification would improve the general health of the population firstly by reducing dependence on combustible fuel and the associated health risks and secondly, by bringing the services of modern medicine and dentistry closer to the community. Medical facilities would benefit from being able to use refrigeration and more advanced electrical equipment. Classroom lighting, educational aids and the ability to offer night classes would help to raise the general standard of education.

Electric lighting would allow residents to stay up longer and spend more time with evening leisure activities, or studying. Lighting is the cheapest electrical appliance and is generally the first to be widely used. In time householders would be able to purchase a wider range of energy saving or labour saving electric appliances. Adequate lighting of homes and public areas in villages would increase feelings of security and possible lead to a reduction in crime rate, road accidents and fires.

The ability to use radio and television is often cited as a major perceived benefit by those who do not have electricity. These two media also present ideal opportunities for educational programmes at village schools, weather information for farmers, etc.

The activities of rural woman in many parts of the world revolve around the household, and since a large number of electrical appliances are geared to easing household chores, it undoubtedly has a major effect on women's lives. However, it is unlikely that electricity would replace traditional fuels for the largest consumers of domestic energy, stoves, heaters etc., since it is these appliances that are the most expensive. Even in household that can afford only electric lighting, the housekeeping tasks of women are made easier in that many activities that previously could only be done in daylight hours, can now be done at night.

Demographic Effects

It has been claimed that rural electrification could halt or slow the urban-rural migration pattern, a phenomenon in most developing countries, by making the villages more attractive to live in and by creating better opportunities. There is no solid proof of this. There have also been attempts at linking electrification with reduced birth-rate, usually based on the rather unscientific assumption that, to paraphrase a Pakistani government official: without electric lighting, "the only recreation at night is procreation (p51)".

While there may be links between electrification and rural development which would cause demographic changes, it is impossible to determine a causal relationship with declining birth rates or migration patterns.

4.11.5. The Cost of Rural Electrification

The cost of a rural electrification project can be broken down into three distinct areas. Firstly, the cost of additional power generation (new power stations) that may be required, secondly the extensions to the existing distribution network (high and medium voltage lines) and thirdly, the low voltage supply from local substations to individual houses.

Generation

The additional generating capacity required for rural electrification depends on the number of houses to be supplied and the "after diversity maximum demand" or AMDM. The number of rural households requiring electrification currently stands at about 2 million, and the rural AMDM is estimated to be less than 1.5 kW per household (Dingley,1988b:12). The capacity required is thus in the region of 3 000 MW. This is equivalent to one large power station, or about 9% of Eskom's capacity at the end of 1989 (Eskom,1990). As discussed in the section on urban electrification in Chapter 3, it can be assumed that a national electrification programme would focus more heavily on urban areas, and of the 350 000 new connections required to eliminate the rural and urban backlog over 20 years, only a small number initially would be rural. With Eskom's existing over capacity, electrification of both urban and rural areas could proceed for a number of years before additional generating plants would need to be built (Dingley,1990:17).

High Voltage Reticulation

Because of the distances covered and the dispersed nature of rural settlements, distribution equipment forms one of the major cost components of a rural electrification programme. The distribution network is generally made up of high voltage lines (132 kV) with step-down transformers to a regional network of 11 or 22 kV lines, with further step-downs to low voltage supply to individual houses. Most "homelands" have easy access to the 132 kV national grid network and it can be assumed that further extension of this grid would not add appreciably to the overall cost. The most substantial grid extension would be in the form of 11 or 22 kV "radial" and "spur" lines to individual villages or concentrated settlements. A typical rural electrification scheme would start with the step-down from a 132 kV line to a number of 22 kV radial lines encircling groups of villages. Spur lines branching out from the radial feeders would run to each village as required. If the 132/22 kV transformer is located near a large town, a number of houses could be supplied without any further lines being built. However, most houses would have to wait until the completion of the radial feeders. Thus the initial cost per household is very high. As more spurs are led to villages and more households connected, the cost per household drops dramatically, only to rise again when lines have to be extended to villages most remote and furthest from the radials. For this reason, a study by Tobich and Dingley (1988) calculated the cost of 22 kV line construction in the Ciskei as R1 100 per household at 50% saturation dropping to a low of R796 per household when about 87% of the population are electrified. Using a slightly different approach, a study by Turner and Dingley (1988) on electrification of the Transkei gave a figure of R1 040 per household (22kV distribution only) for the electrification of 90% of the population. A study in Namaqualand gave a cost of R1 100 per stand for 100% electrification (Borchers,1990).

Low Voltage Reticulation and Housewiring

The final cost item consists of the low-voltage (380 V) reticulation from the 22 kV substation to individual houses, and the cost of the meter and housewiring. To determine the low-voltage reticulation cost, it is necessary to establish, for each village, the actual number of houses to be electrified, the spatial distribution of these houses, and the geographical features of the village. Such a detailed study has not been done. Dingley (1988b:8) estimates the low voltage reticulation in rural areas to cost as least as much as the total figure for urban areas, i.e. around R2 000 per household (excluding housewiring).

Overall Costs

Assuming a per household cost of R1 000 for high-voltage distribution, and R2 000 for low-voltage distribution, the total cost of rural electrification would then be in the region of R3 000 per household, excluding housewiring. Housewiring, usually the responsibility of the householder can be reduced to a minimum using a "Redi-Board", available at around R150. Given that there are approximately 2 million unelectrified rural households, the overall total cost for rural electrification is about 6 billion. In reality, however, this cost would be stretched over many years.

4.11.6. Financing Rural Electrification

Rural electrification projects in developing countries require large amounts of capital and are in most cases heavily dependent on First World loans or grants. Even for relatively wealthy South Africa, the scale of Eskom's activities is largely dependent on the availability of foreign loans. The World Bank, between 1976 and 1978, lent US$3 047 million to five developing countries for electrification of which 7,5% was used for rural schemes. Between 1961 and 1978, the Inter-American Development Bank loaned to Brazil (among others) US$1 052 million for an electrification project whose total cost was US$8 075 million (Cecelski & Glatt,1982:3).

With such large sums being spent, the most important question perhaps to planners is how to make the project worth the money spent. The need for a financial return has produced different results in different countries. In India, for example, electrification programmes have been aimed at improved agricultural irrigation, which accounts for as much as 88% of consumption in some areas. China on the other hand has attempted to establish a rural industrial demand as a base load with irrigation adding on to this. In Costa Rica, El Salvador, Nicaragua and Thailand about 30% of rural electricity supplied is used by the residential sector, while about 60% goes to economically productive rural industrial and agricultural use. Strangely enough, in the Philippines, the figures are approximately reversed, with as much as 60% going to "unproductive" residential use, following a government campaign to reduce support for "communism" in the rural areas (Cowan,1986:3).

The approach to rural electrification programmes and their justification of them depends on the priorities of the supply authority and government. Munasinghe (1988) has broadly categorised three different approaches to rural electrification, discussed below:

- Electrification is used to optimise economic efficiency. Priority of supply would be given to those areas with a high agricultural or industrial potential where electrification would stimulate production, maximise output and growth. Electricity prices would follow the marginal costs of supply, with subsidies (if any) carefully targeted at the very poor only. This would be the easiest and quickest way to recover costs.

- Electricity can be seen as a solution to the provision of basic human needs, providing welfare, social services and improving the income distribution. The economic return in this case is seen to come from the long-term development of the rural areas. Economically depressed regions get the highest priority and pricing is based on "ability to pay" rather than on cost of supply. The scheme would rely initially on a high level of subsidy and financial returns would only be expected in the long-term.
- Electrification schemes can be planned with the aim of minimising the capital cost of the project, while supplying as many consumers in as short a time as possible. Priority would be given to those consumers closest to the existing grid network and to areas with an existing support infrastructure and high population density.

In practice, no single approach is used to the exclusion of others, but their relative weights vary in different countries. It would seem that in developing countries, the more successful electrification schemes are those that have followed the first option i.e. have placed greatest emphasis on the economically productive use of electricity, encouraging its use in agro-industrial and commercial activity, water pumping, and cottage industry. There are important reasons underlying this trend:

- Most developing countries rely extensively on borrowed money which can put a strain on their economies. By targeting electricity at high productivity applications, economic growth accelerates and loans can be more quickly repayed.
- Productive rural industry and areas of high agricultural productivity are more likely able pay for electrification. This reduces the subsidy required and lessens the burden on other sectors of the economy.
- Electricity in the household is often not seen as a basic need by the rural population. There may be other more pressing issues that have priority, such as safe water supply, sanitation, health, education and nutrition, and until these needs are filled, electricity is better applied to rural industry and commerce.

- Rural electrification does not produce spectacular overnight results. Because of the cost of electrical appliances, rural households initially tend to use electricity for only the lowest power applications, such as lighting, radio and TV. Wood and fossil fuels tend to remain the fuels used for high-energy applications such as cooking and space heating. The complete transition to electricity depends to a large degree on a prior economic transition from subsistence to surplus.
- A certain level of infrastructure is required before electricity can realise its full potential. Highly productive areas are likely to already have the basis upon which this can be built.

4.11.7. Conclusion

It is clear that, in comparison with many other developing nations, South Africa is well positioned as far as rural electrification is concerned. It has a competent and experienced electricity supply authority, the necessary technical capacity and skills, and the capacity to locally manufacture most of the material input required. In addition, it has the generational capacity available and a well established existing national grid. South Africa also has a rural population with intimate ties to the modern urban sector, and the advantages and potential benefits of electricity are not unknown to rural people. In short, a rural electrification programme is well within Eskom's capability and, given the funds and the structures to implement it, rural electrification would be a positive step towards the development of rural areas. However, rural electrification is not the final answer, and like any other process of technology transfer, needs to be implemented carefully and with due consideration.

Electricity itself is not a basic need, although it may be the best solution to fulfilling certain basic needs. As such electrification is not a panacea to rural development. Experience in numerous Third World countries has shown that rural electrification on its own is neither sufficient cause nor precondition for economic growth and spontaneous rural development. The success of rural electrification depends on the existing level of development in the region, and the need for electricity in households, rural commerce and agricultural industries. Where these factors are significantly high, electrification is likely to stimulate the desired economic growth.

Obviously, all parts of the rural areas are not developed to the same extent and it is to the benefit of the country as a whole that resources for electrictrification first be diverted to those areas that really need it. The essential first step is the accurate assessment of rural needs in various areas and how electricity can fulfill them. The second step is an accurate assessment of the ability of the existing infrastructure to support and get maximum benefit from electrification.

There will be many situations where electrification is not a high priority and where other needs take precedence. However, this does not mean that it should not be shelved until certain pre-conditions are first met. By including electrification in a comprehensive development "package", a number of other related development issues such as water supply, education and agricultural production could benefit.

More than most rural development programmes, rural electrification requires large amounts of capital to be invested and tied up for many years to yield almost negligable cash returns. In conventional terms, rural electrification is essentially a non-profit venture and financing can thus be a serious problem. It is a fact of rural electrification programmes that the major portion of the initial capital has to come from the state. It is also likely that the full amount will not be recoverable on market related terms, and a degree of subsidisation is inevitable. However, subsidisation is a double-edged sword, and it is essential that the rural communities are drawn into the process and that their own resources are fully mobilised.

The problem is how to reduce subsidies to a minimum without limiting electricity to so few people that it becomes a meaningless exercise. It is not unlikely, given the degree of "modernisation" of rural South Africa, that rural households will be prepared to pay substantial amounts, and even get into debt, for the priviledge of being connected to the grid. This has been noted in a number of other Third World countries. What is required is an assessment of how much rural households are prepared to pay and what mechanisms exist for them to obtain credit and so spread the initial costs over a period of time. The mobilisation of community resources would require an effective extension service to advertise and advise on rural electrification (as exists for white farmers), and to facilitate financing arrangements between the local community and the authorities.

Rural electrification needs to be directed by a sound policy. While the most cost effective method may be to provide electricity to those who can immediately afford it, this may not be the best policy in the long term, particularly if rural electrification is seen as an essential ingredient in rural development as a whole. If rural households must bear some of the costs, a rural electrification programme is obliged to be flexible enough to follow local initiatives which are supported by a genuine commitment on the part of the local communities. Mechanisms that bring local community leadership into the decision making process, along with the supply authority, state departments and NGOs, should be encouraged.

CHAPTER 5

STRATEGIES FOR HOUSEHOLD ENERGY SUPPLY IN UNDERDEVELOPED AREAS

5.1. Introduction

Technology is fundamental to the production of goods and services, and the generation of wealth and growth, and has always been the central theme in development strategies. However the kind of technology and the way in which it is used has differed with different development strategies. Early development discourse maintained that the rapid transfer of "modern" technologies from developed countries to less developed countries would accelerate their industrial growth and allow them to "catch-up" with the developed countries. It was also thought that the transfer of new ideas and techniques would filter down through all levels of the society eventually leading to the spontaneous local adoption of these new ideas, the creation of a higher level of indigenous technology and the "modernisation" of these societies. In many countries (including South Africa), the effective use of imported western technology led to great improvements in the per capita income and health and educational levels. The benefits however did not always reached all levels, and large sections of the population in these countries remain unemployed and poverty stricken.

With the realisation that a technology, highly productive in one context, does not necessarily reproduce the same effect in another, theorists argued that technologies introduced should more accurately reflect the abundance or scarcity of available resources (most importantly, labour and capital) in the developing countries. This idea was further developed into the "intermediate technology" of Schumacher (1973) and so-called "appropriate technology", where the introduction of new technologies was focused primarily on the needs of the rural poor and marginalised sections of the population.

All of these theories however, tend directly or indirectly, to view the poor and underdeveloped as isolated from the mainstream developed economy, with their condition due to certain inherent deficiencies. Given that these deficiencies do not allow the evolution of suitable technology to satisfy their needs, development is seen as an unproblematic process whereby indigenous, inefficient technology is replaced by an imported, more efficient, more productive or more "appropriate" form. This view thus assumes that radical social change can be brought about without prior alteration of the social, economic and political structures. However, poverty in the "third-world" is not a static condition that has always existed in modern times, nor is it due to deficiencies inherent in the population. What these approaches have failed to recognise, is the structural economic relation between rich and poor, and between powerful and weak, whereby the underdevelopment and impoverishment of the "third-world" is part of the same process that generates wealth and prosperity in the "first-world". It is a process that continues still and one which cannot be reversed merely by the judicious application of technology.

A large body of historical evidence shows that populations in South Africa that are today considered underdeveloped have not always been so. There are some fascinating accounts (Bundy,1988; Keegan,1988; Beinart,1984; Davenport,1987) of a thriving and technically well developed African agriculture economy around the turn of the century throughout the country. This was until the need for cheap labour on white farms and on the mines led to harsh restrictive measures. The abolition of black share-cropping on white-owned land, increased taxation and finally, the 1913 and 1936 Land Acts, were instrumental in causing the decline of autogenous black farming. Current indigenous agricultural productivity in the "homelands" has been reduced to a secondary though necessary activity for supplementing low wages. The unsophisticated and inefficient cultivation of "homeland" areas is not a result of "tradition", but is enforced by lack of capital and reduced access to resources. The structural relations between the "first-world" and "third-world" in South Africa have undoubtedly had an effect on the opportunities as well as the attitudes of the underdeveloped population towards technical change, and it is not surprising that under these conditions there has been minimal adoption of "new" technologies by "third-world" South Africa, no matter how appropriate.

The discussion in Chapter Two has presented household energy use patterns and energy needs in the "homelands" and black urban and fringe areas as just one of the "symptoms" of underdevelopment. The eradication of these symptoms, as well as their underlying roots has to be tackled through some form of intervention or process of development, a part of which will include the introduction of new technologies. The theory and practice of development in the past has emphasized employment, growth and productivity, reflected in the preoccupation with the form of technology, be it capital or labour intensive, imported or locally made. More recently, with the wide acceptance of "basic needs fulfillment" as the most effective form of intervention, the emphasis has returned to the real objectives of development.

Basic needs fulfillment is not so much a development strategy as an approach to development in that it indicates a measurable goal to be met rather than prescribing the means of meeting this goal. Streeten et.al. (1981:21) list four advantages of the "basic needs" approach to development over previous philosophies.

- It returns to the original objective of development, that is, to provide all with the opportunity for a full life.
- It aims for concrete measures to benefit specific vulnerable groups, and is not tied up with abstract or hard to measure goals such as income, employment and GNP which often mask disparities in the distribution of income and wealth.
- It is popular in developing countries and amongst aid-donating countries because of its relative simplicity and direct approach and is thus able to mobilise more resources and support.
- It is the logical starting point for all activities related to the eradication of poverty, and has great potential as an intellectual tool due to its power to tackle seemingly unconnected problems in an integrated way.

In chapters Three and Four, energy technologies with potential application in developing areas have been reviewed, with passing reference to the need for a context in which these technical solutions could be applied. It is within the context of basic needs fulfillment, that a framework for the application of energy technologies in underdeveloped areas in South Africa has to be developed.

5.2. Basic Energy Needs

The notion of "basic needs fulfillment" as a development strategy has as its justification, the argument that the development process cannot proceed unless poverty-stricken households are first able to satisfy those basic needs essential for a full and active life. Basic needs fulfillment is seen not merely as an act of charity toward the poor and disadvantaged, but rather as a means to free them from the cycle of poverty and allow them to become active and productive members of the economic and political community. Moves towards fulfilling basic needs would raise standards of living, encourage productivity, and lead to more rapid growth. If focussed on rural areas, migration pressures would be alleviated, reducing the costly burden of providing services in fast-growing cities. With a large proportion of the population poor, the internal market is effectively reduced to a fraction of its potential. With a higher general standard of living, the need for consumer goods and services would increase, stimulating local industry to provide them. Developing countries would then produce more of what they consume and consume more of what they produce, trading more (and on more equal terms) with other developing countries, and reducing their dependence on developed countries.

Most economists and planners, agree that basic needs (BN) programmes should ensure minimum standards of nutrition, shelter, health, education and employment. Yet there are different thoughts on how these needs are defined and how they can be fulfilled. The first difficulty lies in defining what constitutes basic needs in a particular situation. Steward (1985:4) identifies two extreme approaches in determining the basic needs basket of goods and services:

- The "chicken in every pot" view assumes a fixed set of goods and services that every human needs in order to live a full and decent life. Strategies can then be proposed which aim to fulfill these needs and progress can be easily measured.

- The "full-life objective" view selects and ranks basic needs goods and services on what they can contribute towards this objective. In practice, BN goods and services are wanted not for themselves but for the conditions they create and thus the BN basket will differ for every section of society and degree of development, and will change with time.

Further differences in approach arise from questions such as:

- who should determine basic needs, the BN consumer or the BN provider;
- the degree of mix between material goods and non-material, non-economic aspects in the BN basket; and
- which groups in society should be the primary targets of a BN strategy.

In underdeveloped areas in South Africa, the predominant energy requirement is for essential household activities like cooking, water heating, space heating and providing light. A basic energy needs strategy should aim at providing for all households, an adequate and affordable supply of energy for these activities. One obvious feature of chapters 3 and 4 is that not all the technologies reviewed appear to be suitable for meeting basic energy needs at all levels. Those that do not, have been included nevertheless to illustrate problems inherent in technologies that seem, on the surface, appropriate. Lisk (1985 in McClintock,1988) suggests three principles which should direct the approach to a basic energy needs strategy. These are specifically for rural areas, but apply also to the urban situation. They provide a sound basis for the application of energy technologies in underdeveloped areas and are as follows:

- Energy supplies selected should be affordable by the poorest of the community. This does not exclude more "expensive" supplies, but affordability should be a priority.
- Availability of, and access to appropriate energy technologies must be increased to a maximum.
- In rural areas particularly, the local production of energy sources from the natural environment should be achieved on a sustainable basis.

5.3 Energy Strategies for Urban Areas

In underdeveloped urban areas, basic household energy needs are chiefly met by fuels such as candles, wood, paraffin and coal, and for those that require electricity, car batteries are the only alternative. For households, meeting basic energy needs is expensive and the fuels used are totally inappropriate to densely populated urban environments.

By far the most obvious approach in providing adequate and affordable energy supply is to electrify all urban areas. Many households in established black townships are still without electricity, and "squatter-camps" and informal settlements, despite their makeshift appearance, are a permanent feature of our metropolitan centres, and cannot be simply ignored in the planning of energy supplies. Electrification of urban areas will eliminate many of the pollution, health and fire risk problems associated with the burning of fossil fuels. Surveys, as well as recent electrification projects, indicate that the desire for electricity is matched by the ability to pay for it. It has been shown that coal, paraffin and wood are no cheaper than electricity in terms of the useful energy they deliver. In fact, households can end up paying more for inefficient, "lower quality" fuels. There are of course problems. Electrification of residential areas requires a large capital investment and yields a low return which make justification on narrow economic grounds difficult. In addition, for households operating on a tight budget, the cost of housewiring and new appliances may be prohibitive, and those having difficulty in paying may be "unplugged" at the whim of the supply authorities. These problems however could largely be overcome through innovative financing, technological ingenuity, and a sympathetic community-based approach. Since the state indirectly controls access to electricity generation and distribution, all that is really required is a serious commitment on the part of the state to find a way of offering low-income black South Africans the same basic services enjoyed by others.

One of the problems with electrification of low-income households is its slow uptake. Despite the desire for electricity, many of the poorer households cannot afford "full" electrification and tend still to rely on a mix of fuels. This is particularly so in the case of activities which draw a lot of power or require the purchase of expensive electrical appliances, such as cooking, water heating and space heating. Once the availability of electricity has been guaranteed, it may take a number of years before households drop their dependence on other fuels. There is thus a significant place for energy technologies which can fill this "gap" by offering cheap and energy efficient alternatives which can be offered along with electricity as a "household energy package".

Solar water heating could help reduce household electricity requirements and thus help cut household bills. Ironically, the major constraint to the widespread adoption of solar water heating is the relatively low cost of electricity units, and in most cases, the savings gained by using a solar system do not warrant the initial capital expense. This situation will not improve unless the price of solar water heaters drop or the unit charge of electricity increases. Another constraint is the requirement of a piped water supply to the house, which effectively limits the market to formal black townships. The most promising areas for solar water heater application is in new housing developments, where a solar unit can be included as a built-in feature of the house. This will allow residents to manage with a smaller electric geyser and the capital cost of the unit can be included in the cost of the house to be repaid over a number of years.

Many urban households have large sums invested in solid fuel burning appliances, typically, coal or wood burning stoves. Since they would be unable to replace these immediately, the provision of a cheaper alternative to coal and wood could find application. One such alternative is a solid fuel manufactured cheaply from coal and wood wastes. While this has the benefit of allowing an efficient use of waste products, it requires a large capital investment in manufacturing plant.

Another way of reducing overall energy requirements is the design of houses to minimise the need for space heating. There are a number of design modifications that could substantially improve the thermal efficiency of low-cost housing without adding significantly to the overall construction cost. These include roof insulation, north-facing aspect and sufficient roof overhang among others. The impact of this is limited by the slow progress in provision of mass housing.

Photovoltaic (PV) panels are a clean, compact and elegant technology, producing electricity directly from sunlight. They have no moving parts, and require almost no maintenance. However, at current PV panel prices, even well-off households would only be able to afford systems small enough to run a few low-power lights and perhaps a TV or hi-fi system. Their main advantage to the householder is that they are self-contained and portable, and if prices drop, no doubt they will find a ready market in areas where electrification is still a long way off.

5.4 Energy Strategies for Rural Areas

In rural areas, where capital resources of the average household are very low, and expectations thus focussed on the very short-term, attention has to be paid to the affordability and availability of energy supplies. There are three "legs" to a rural energy strategy aimed at addressing the problem of diminishing wood supplies, namely, establishing a renewable and sustainable supply of fuelwood, encouraging the more efficient use of fuelwood, and the substitution of wood with other fuels. Since no single one of these strategies is likely to yield the desired result, a combination of all three is required.

The first "leg", the creation of a renewable and sustainable supply of fuelwood demands an extensive range of afforestation programmes. There are different afforestation techniques, from massive plantations established and managed by central organisations, to initiatives encouraging individual households to plant a few trees on their own land, for their own use. Between these two extremes are a number of other afforestation techniques. Planting trees would appear to be a simple, logical response to the shortage of fuelwood since seedlings can be bought cheaply and the planting and nurturing of trees is relatively easy. However, trees may take 5 to 10 years to mature, and there is little incentive for cooperation from families who's energy needs are immediate. There are other complications too. Forests require suitable land and may reduce the area available for crops and grazing. Also, "traditional" land tenure arrangements introduce uncertainties around who owns the trees, who is responsible for their care and who benefits from their eventual harvesting. One of the more promising afforestation technologies is agroforestry, where trees are grown as a crop, together with other crops, serving as windbreaks, soil stabilisers, and sources of fuelwood and animal fodder. There is clearly room for more research into the selection of suitable hardy, fast-growing species, and ways in which agroforestry could be made attractive to rural farmers. Planting enough trees to satisfy fuelwood demand is clearly be an enormous task, and would require the massive mobilisation of state resources, both directly and indirectly in the form of large state plantations (where applicable), support to NGOs, village organisations and small farmers, the establishment of nurseries and wide-scale extension support.

A strategy to create a renewable and sustainable supply of fuelwood could also include the manufacture and marketing of wood-derived fuels such as charcoal. In some areas, the wood shortage has led to the commercialisation of fuelwood. Since charcoal has a higher energy density than wood, transport costs per unit energy are in theory lower than wood. There are a number of sources for the manufacture of charcoal including plantation and sawmill waste, woodlots where the trees have grown too large for use in open fires or stoves, plantations which can be dedicated to charcoal production, and, in some areas, the eradication of alien bush. There is however, no tradition of charcoal manufacture or of its use in South Africa, and thus no ready market. The fractional saving gained by transporting charcoal over wood is also not great enough to make it a very attractive option for wood vendors. There is however, a lucrative local industrial and export market and possibly the brightest future for charcoal lies in a symbiotic relationship with afforestation, where a plantation's harvest could be split between fuelwood, sold at nominal charge for local needs, and charcoal sold on the open market. The profits generated by charcoal making could be used to sustain the whole plantation and subsidise the price of fuelwood. In a similar manner, there is great potential for multi-use trees, where besides fuelwood, the trees also supply fruit, animal fodder and building materials.

The second "leg", encouraging the more efficient use of fuelwood, must centre around changing existing wasteful habits. The leading strategy in this regard is the introduction of fuel efficient wood-burning stoves. Stoves can be made to double the efficiency of open fires and thus halve the required fuel consumption. However, world-wide experience has shown that fuel efficient stove dissemination programmes are not always successful in reducing wood consumption, particularly if the sole benefit of the stove is that it uses less wood. There are several reasons for the failure of many stove programmes. These include poor design, the lack of repeatability between laboratory conditions and the real world, and the tendency for households to use more wood once they own a stove. Despite this, there is considerable potential for lightweight, low-cost metal stoves which operate at a high efficiency in addition to increasing living standards through improving kitchen aesthetics, removing smoke from the cooking area, and offering oven and hot water attachments.

The third "leg" of a rural energy strategy, to encourage the substitution of wood with other energy sources, is the most difficult. Where wood is in short supply, this is happening by default, as households are forced to switch to dung, twigs and grasses, or spend hard-won cash on paraffin or coal. But this only increases the need for adequate and affordable energy supplies. The main problem with this part of the strategy is that switching from wood to another energy source usually implies an investment from the household (in time, effort or money) which may not be worth the reward, or may not be within the means of many poorer households. The construction of a biogas unit, for example, requires an investment in capital and a considerable degree of skill. Its operation requires skilled effort and commitment. Even if these are available, a respectable gas production rate further requires plenty of water, a warm climate, and an animal husbandry method that allows the easy and regular collection of dung. In the light of these constraints, biogas becomes less viable.

Solar cooking and solar water heating appear on the surface to be attractive substitutes to the woodfire. Solar cookers in particular have gripped the imagination of many engineers and backyard inventors and there is a plethora of ingenious, efficient solar cooker designs available. However, cooking is perhaps one of the most culture-bound of all the energy using activities, and a change in cooking practices demanded by solar cookers cannot be easily achieved. Low-cost solar water heaters can be easily built from scrap materials and require not too much effort to use. However, the result of keeping costs and complexity down, are simple designs which do not provide the water as hot nor as quickly as can be obtained from heating it on a fire. The widespread use of solar water heaters would require a substantial dissemination effort and if hot water is not seen by rural households as a major priority, this effort would be better directed elsewhere.

The section of passive solar design of rural dwellings has shown that traditional dwellings invariably incorporate aspects of passive solar design to good effect. It has also argued that the influence of "western" culture (and building materials) has forced a change away from the traditional to possibly more durable, but less thermally efficient designs. There are possibly ways of improving on some designs, but as there are almost as many house designs as there are rural households, it becomes impossible to provide a single technology which would radically improve thermal comfort of all possible designs. To improve the thermal comfort of rural dwellings requires, not a new technology, but rather the education of rural builders in the thermal characteristics of building materials and the art of passive solar design.

A further way to substitute the use of wood as a major fuel is by providing rural areas with electricity. Rural households in the "homelands" have essentially no access to electricity, and most rural electrification programmes have been directed at white-owned farmland. Photovoltaics offer an elegant and attractive method of meeting low-power electricity needs such as lighting. However, their cost at present puts them beyond the means of most rural households. Although indications are that the prices will drop in the future, photovoltaic systems require a large initial investment, and would still be available only to those who could meet this, or who would be able to obtain credit.

Providing rural areas with grid electricity is a massive undertaking and one that would offer many technical challenges and require massive state resources. Experience in other countries shows that rural electrification alone is neither sufficient cause nor a precondition for rural development, and possibly the biggest argument against rural electrification is the high financial cost weighed up against a rather uncertain return, both in cash terms, and in the extent that electrification stimulates rural development. However, there is an urgent need for more research on cost-effective methods and appropriate standards for rural electrification since there is no doubt that the demand for electricity in rural areas will increase, and that rural electrification will be inevitable.

5.5 Conclusion

For too long, the energy needs of households in black urban areas, informal settlements and rural "homelands" in South Africa have been overlooked. Energy planning and the distribution of energy resources have focussed on the needs of a small but powerful industrial and wealthy urban sector. The energy crisis now facing underdeveloped areas is severe and demands urgent attention.

In urban and peri-urban areas which are denied electricity, households are forced to use fuels which are expensive and inferior, and totally inappropriate to crowded urban conditions. With urbanisation growing at an overwhelming rate, the lack of electrification and other services is compounding an already unstable political environment. In rural "homelands", the growing fuelwood scarcity is further impoverishing households by forcing them to spend more time, effort and hard won cash on a resource which has traditionally been freely collected. The environmental cost of continually deteriorating tree stocks is likely to be severe.

The aim of this thesis is to provide an overview of possible technical solutions for the energy problems in underdeveloped areas by reviewing a range of energy technologies and latest work in these fields. It is hoped that this overview has highlighted the potential of various technologies to make a real impact on the energy problems in urban and rural areas. While focussing on technical aspects, this thesis has also attempted to identify and define the "energy problems" as part of a much wider problem of poverty and inequality. It is clear that a programme to eradicate inequalities in energy supply has to be accompanied by eradication of other forms of inequality. Basic needs fulfillment provides a context in which energy problems can be tackled along with other problems in underdeveloped areas.

REFERENCES

Chapter 1 - Introduction

CARDOSO, F. (1973) "Dependency Revisited", Hackett Memorial Lecture, Institute of Latin American Studies, University of Texas, Austin.

EBERHARD, A.A. (1984) "Energy and Poverty in Urban and Peri-urban Areas Around Cape Town", 2nd Carnegie Inquiry into Poverty and Development in Southern Africa, Conference Paper No. 155, SALDRU, University of Cape Town.

GANDAR, M.V. (1983) "The Utilisation of Trees and the Impact on the Environment: A Study in Mahlabatini District, KwaZulu, Part 1 - The Domestic Use of Wood: A Socio-Economic View.", Inst of Natural Resources, Univ of Natal, Pietermaritzburg.

RODNEY, W. (1974) "How Europe Underdeveloped Africa", East Africa Publishing House, Nairobi.

Chapter 2 - Energy Consumption Patterns in Underdeveloped Areas and the Distribution of Energy Resources in South Africa

ARON, J., EBERHARD, A.A. & GANDAR, M.V. (1989) "Demand and Supply of Firewood in the Homelands of South Africa", 2nd Carnegie Inquiry into Poverty and Development in Southern Africa, Post Conference Series No.27, SALDRU, University of Cape Town.

BARNETT, BELL & HOFFMAN (1982) "Rural Energy and the Third World", Pergammon.

BEST, M. (1979) "The Scarcity of Domestic Energy: A Study in Three Villages", SALDRU Working Paper No.27, University of Cape Town.

DEPT OF HEALTH (1977) "Implikasies van die Voorsiening van Elektrisiteid aan Bantoedorpe", Dept. of Health, Pretoria.

DEPT OF ENVIRONMENTAL AFFAIRS (1986) "Report on the Commercial Timber Resources and Primary Roundwood Processing in South Africa 1984/85", Directorate of Forestry, Pretoria.

DEPT OF MINERAL AND ENERGY AFFAIRS (1989) "South Africa's Mineral Industry - 1988", Minerals Bureau, Pretoria.

DINGLEY, C.E. (1988) "Macro Cost Estimate for a National Electrification Programme", Interim Report No.15, Dept of Electrical Engineering, University of Cape Town.

DINGLEY, C.E. (1990) "Electricity for All in South Africa: The Need and the Means", Department of Electrical Engineering, University of Cape Town.

EBERHARD, A.A. & DICKSON, B.J. (1987) "Energy Consumption Patterns and Alternative Energy Supply Strategies for Underdeveloped Areas of Bophuthutswana", Energy Research Institute, University of Cape Town.

EBERHARD, A.A. (1984) "Energy and Poverty in Urban and Peri-urban Areas Around Cape Town", 2nd Carnegie Inquiry into Poverty and Development in South AFrica, Paper No 155, SALDRU, University of Cape Town.

EBERHARD, A.A. (1986a) "Energy Consumption Patterns in Underdeveloped Areas in South Africa", Report No.94, Energy Research Institute, University of Cape Town.

EBERHARD, A.A. (1986b) "South African Energy Crisis: Some Suggested Strategies", 2nd Carnegie Inquiry into Poverty and Development in Southern Africa, Post Conference Series No 13, SALDRU, University of Cape Town.

EBERHARD, A.A. (1988) "The Potential for Renewable Energy Technologies in South Africa", in Eberhard A.A. & Williams A.T. (eds.) Renewable Energy Resources and Technology Development in Southern Africa, Elan Press, Cape Town.

EBERHARD, A.A. (1989) "Energy Consumption Patterns and Supply Patterns in Underdeveloped Areas in South Africa", Alternative Energy Supply Options for Developing Southern Africa, Conference Proceedings, Development Bank of SA & Solar Energy Soc. of SA, 2-3 February, Johannesburg.

ESKOM (1987) "Eskom to Boost Electrification of Developing Areas", Press Release, 25 August.

ESKOM (1990) "Statistical Yearbook - 1989", Eskom, Johannesburg.

FOLEY, G. (1988) Discussion Paper on Demand Management, World Bank Eastern and Southern Africa Regional Seminar on Household Energy Planning, Harare, February, Panos Institute, London.

FOLEY, G., MOSS, P. & TIMBERLAKE, L. (1984) "Stoves and Trees", Earthscan, London.

GANDAR, M.V. (1983) "The Utilization of Trees and the Impact on the Environment: A Study in Mahlabatini District, KwaZulu, Part 1", Inst. of Natural Resources, Univ. of Natal, Pietermaritzburg.

GANDAR, M.V. (1984) "Firewood in KwaZulu: Quantities and Consequences", Energy for Underdeveloped Areas Conference, Energy Research Institue, University of Cape Town, 9-10 February.

GANDAR, M.V. (1988) "The Utilisation of Trees and the Impact on the Environment: A Study in the Mahlabatini District, KwaZulu", Report for the South African Savanna Ecosystem Project, CSIR, Pretoria.

HANSARD (1987) Questions in the House of Assembly, 26 May.

LEADERSHIP (1986) "Eskom" Leadership Corporate Profile, October

LIENGME, C.L. (1983) "A Study of Wood Use for Fuel and Building in an Area of Gazankulu", Bothalia, Vol.14, No.2, pp245-257.

LONG, R. (1986) "The Availability and Cost of Coal in South Africa", International Energy Agency (Coal Research), London.

MOLLER, V. (1985) "Rural Blacks Perceptions of Basic Needs Fulfillment", Centre for Applied Social Studies, University of Natal, Durban.

RIVETT-CARNAC, J.L. (1979) A Strategy for Electrification of the Black Townships in and Around Durban and its Impact on the Energy Situation in South Africa, Mimeo, Urban Foundation, Durban

SAIRR (1987a) Social and Economic Update, No.1, South African Institute for Race Relations, 27 April.

SAIRR (1987b) Social and Economic Update, No.2, South African Institute for Race Relations, 27 July.

SIMKINS, C.E.W. (1985) Patterns of Urbanisation in South Africa, Economics Learning Resource No.7, School of Economics, Univ. of Cape Town.

SORFA, P. (1983) "Study on Availability and Demand for Wood Residues in Respect of Potential Development Trends", Report No.HOUT/287, CSIR, Pretoria.

VILJOEN, R.P. (1989) "Domestic Energy Transition in South Africa in the Context of Rapid Urbanisation", M.App.Sc., Faculty of Engineering, University of Cape Town.

WHITE, R. (1979) "A Handbook for Village Woodlot Planning and Management", Hukuntsi.

WILSON, F. & RAMPHELE, M. (1989) "Uprooting Poverty : The South African Challenge", David Philip, Cape Town.

Chapter 3 - Technologies for Household Energy Supply in Urban Underdeveloped Areas

3.2. Grid Electrification

BROOKING, T. (1988) Untitled, Eskom, Johannesburg.

CAPE TIMES "Now Credit Power Hits Home" 19 August 1989.

DINGLEY C.E. (1988a) "A Review of Electrification Programmes in Six Countries", Dept of Electrical Engineering, University of Cape Town.

DINGLEY, C.E. (1987), "Evaluation of Report on Soweto Electrification", Report for the National Programme for Energy Research, 12 February.

DINGLEY, C.E. (1988c) "An Approach to Financing", Interim Report No.19, Dept of Electrical Engineering, University of Cape Town.

DINGLEY, C.E. (1988b) "Macro-Cost Estimate for a National Electrification Programme", Interim Report No.15, Dept of Electrical Engineering, University of Cape Town.

DINGLEY, C.E. (1990) "Electricity for All in South Africa: The Need and the Means", Dept of Electrical Engineering, University of Cape Town.

EBERHARD, A.A. (1986) "Energy Consumption Patterns in Underdeveloped Areas in South Africa", Report No.94, Energy Research Institute, University of Cape Town.

EKSTEEN, L.J. (1990) "Report on Electrification of Coloured Areas", Course Material, Department of Electrical Engineering, University of Cape Town.

ESKOM (1987) "Eskom to Boost Electrification of Developing Areas", Press Release, 25 August.

ESKOM (1990) "Statistical Yearbook - 1989", Eskom, Johannesburg.

FINANCIAL MAIL "Removing the Power", 4 March 1988.

GERVAIS, J.S. (1987) "An Analysis of the Soweto Electrification Project", Report for the Foundation for Research and Development, Pretoria.

HANSARD (1987) Parliamentary Proceedings No.13, "Questions and Replies", 7-11 September, pp 835-6, Government Printer, Pretoria.

LOUW, C.W., GRAUPNER, O.F. & LLOYD, S.M. (1990) "Electricity Generation: Its Environmental and Social Costs", in Issues Affecting Future Electricity Strategies for South Africa, Seminar Proceedings, 25-26 April, NEC/ESKOM.

MIE (1980) "Electrification of Soweto", Supplement to Municipal Engineer, Sept/Oct.

PLANACT (1989) "The Soweto Rent Boycott", Report for the Soweto Delegation, Planact, Johannesburg.

ROOHANI, V. (1987) "The Electrification of Greater Cape Town", Undergraduate Project, 2 November, Dept. of Electrical Engineering, Univ. of Cape Town.

SAIRR (1987) Social and Economic Update, No.2, South African Institute for Race Relations, 27 July.

SCHOLTZ, G.R. & DINGLEY, C.E. (1988) "Evaluation of Different Metering and Billing Systems", Interim Report No.17, Dept of Electrical Engineering, University of Cape Town.

SCHOLTZ, G.R. (1988) "Vulindlela Electricity Survey" Interim Report No.9, Dept of Electrical Engineering, University of Cape Town.

VAN DER SPUY (1981) "The Electrification of Greater Soweto: Its Socio-Economic Impact", Unpublished Paper, Sept.

VILJOEN, R.P. (1989) "Domestic Energy Transition in South Africa in the Context of Rapid Urbanisation", M.App.Sci Thesis, Faculty of Engineering, University of Cape Town.

3.3. - Photovoltaics

BORCHERS, M.L. (1989) "A Decision Making Tool for Assessing Grid Electrification Versus Stand-Alone Power Supply Options for Remote Users" M.Sc.(Eng) Thesis, Energy Research Institute, University of Cape Town.

COWAN, W.D. (1989) "Small Photovoltaic Systems for Educational Purposes", Conference Proceedings, Alternative Energy Supply options for Developing Southern Africa, Development Bank of Southern Africa / Solar Energy Soc. of SA, 2-3 Feb 1989, Jhb, pp 11.15

EBERHARD, A.A. (1984) "Energy and Poverty in Urban and Peri-Urban Areas Around Cape Town", 2nd Carnegie Inquiry into Poverty and Development in South Africa, Paper No.155, SALDRU, University of Cape Town.

MULLER, D. (1988) "The Use of Small Photovoltaic Systems for the Electrification of Off-Grid Homes", M.Sc. Thesis, Energy Research Institute, University of Cape Town.

SINCLAIR, D.J. (1989) "A Review of International and Local Developments in Photovoltaic Technology and Economics for Developing Countries", M.Sc (Eng) Thesis, Energy Research Institute, University of Cape Town.

3.4. Briquetted Solid Fuel

GROBBELAAR, C.J. (1986) "South African Discard and Duff Coal: A National Inventory", Dept. of Mineral and Energy Affairs, Pretoria.

PETRIE, J.G. & EBERHARD, A.A. (1989) "The Use of Waste Derived Fuels for Energy Supply in Underdeveloped Areas in South Africa", International Journal of Energy Research, Vol.13, pp23-38.

SORFA, P. (1983) "Study on Availability and Demand for Wood Residues in Respect of Potential Development Trends", Report No.HOUT/287, Council for Scientific and Industrial Research, Pretoria.

WILLIAMS, A.T. & EBERHARD, A.A. (1988) "The Potential for the Production of Energy from Biomass in South Africa" in Eberhard,A.A. & Williams,A.T. Renewable Energy Resources and Technology Development in Southern Africa. Elan Press, Cape Town.

3.5. Solar Water Heating

BASSON, J.A. (1988) "Results of an Integral Solar Water Heater Research/Demonstration Project", in Eberhard, A.A. & Williams, A.T. (Eds) Renewable Energy Resources and Technology Development in South Africa, Elan Press, Cape Town.

CAWOOD, W.N. (1981) "Financial Incentives for the Installation of Solar Water Heating Systems", Energy, October, pp9

CAWOOD, W.N. (1988) "State of the Art in Solar Water Heater Development in South Africa", in Eberhard, A.A. & Willians, A.T. (Eds.) Renewable Energy Resources and Technology Development in Southern Africa, Elan Press, Cape Town.

ENERGY RESEARCH INSTITUTE (1990) "Solar Water Heating", Pamphlet

ESCOM (1990) Statistical Yearbook - 1989, Eskom, Johannesburg.

MCLEAN, D., BASSON, J.A. & JAMMINE, E.J. (1985) "Hot Water Use in Low-Income Households and the Ability of Integral Solar Water Heaters to Accommodate these Requirements", Report BOU/75, CSIR, Pretoria.

MUHLENBRUCH-TEGIN, A. (1988) "The Solar Resources of South Africa" in Eberhard, A.A & Williams A.T. (Eds), Renewable Energy Resources and Technology Development in South Africa, Elan Press, Cape Town

STANDER, B.A. & BASSON, J.A. (1982) "Opname van Huishoudelik Sonwaterverwarmingstelsels", Conference Proceedings: Solar '82, CSIR, Pretoria.

STASSEN, G. (1988) "The Solar Water Heating Market in South Africa", in Eberhard, A.A. & Williams, A.T. (Eds.) Renewable Energy Resources and Technology Development in Southern Africa, Elan Press, Cape Town.

STERNE, M.P. (1985) "The Economics of Subsidising Domestic Solar Water Heating", M.B.A. Thesis, Faculty of Business Administration, University of the Witwatersrand, Johannesburg.

3.6. Energy Efficient Housing

BACK, D. (1987) "A Review of Available Micro-Computer Design Packages for Passive Solar Design of Low-Cost Dwellings", Report No. INT084, Energy Research Institute, University of Cape Town.

BASSON, J.A., PAGE-SHIPP, R.J. & JOHNSON, M. (1986) "The Garsfontein Low-Energy Experimental Housing Project - Final Report", Research Report No. BRR 576, NBRI, CSIR, Pretoria.

BIRRER, W.A. (1988) "the Design of Economical Energy-Efficient Buildings", in Eberhard, A.A. & Williams, A.T. (Eds.) Renewable Energy Resources and Technology Development in South Africa, Elan Press, Cape Town.

MATHEWS, E.H. (1985) "The Prediction of Natural Ventilation in Buildings", D.Eng Thesis, Potchefstroom University for Christian Higher Education.

NBRI (1987) "Low Cost Housing", NBRI Special Report No.BRR/642/1987, CSIR, Pretoria.

O'DONOVAN, M. (1988) "Review of the Use of Microcomputer-Based Design Tools for Passive Solar Design of Low-Cost Housing in South Africa", in Eberhard, A.A. & Williams,. A.T. (Eds.) Renewable Energy Resources and Technology Development in Southern Africa, Elan Press, Cape Town.

SAIRR (1987) Social and Economic Update, No.1, South African Institue for Race Relations, 27 April.

STEENKAMP, I.L. (1988) "Computer Thermal Prediction with the CR-Method", in Eberhard, A.A. & Williams, A.T. (Eds.) Renewable Energy Resources and Technology Development in South Africa, Elan Press, Cape Town.

WENTZEL, J.D., PAGE-SHIPP, R.J. & VENTER, J.A. (1981) "The Prediction of the Thermal Performance of Buildings by the CR-Method", Report BRR 396, NBRI, CSIR, Pretoria.

Chapter 4 - Technologies for Household Energy Supply in Rural Underdeveloped Areas

4.2. Afforestation

ANON (1985) "Forestry in KwaZulu", Wood SA, Oct, pp15-26.

ARENHOLD, A.A. (1983) "Forestry Quo Vadis: Supply from Potential Afforestable Area", SAIF Symposium.

ARON, J., EBERHARD, A.A., & GANDAR, M.V. (1989) "Demand and Supply of Fuelwood in the Homelands of South Africa", 2nd Carnegie Inquiry into Poverty and Development in South Africa, Post Conf. Series No.21, SALDRU, University of Cape Town.

BEMBRIDGE,T.J. & TARLTON,J.E. (1986) "Ciskei Woodlot Survey and Fuelwood Strategy", 11 June, University of Fort Hare, Alice.

DBSA (1985) "Local Energy and Forestry Programme", Project Appraisal, Development Bank of Southern Africa, 22 December.

DBSA (1986) Proceedings - Workshop on Afforestation in a Development Context, Development Bank of Southern Africa, Johannesburg, 18 June.

DEPT OF ENVIROMENTAL AFFAIRS (1982) "Forestry Guide Plan for South Africa", Division of National Forestry Planning, Directorate of Forestry, Pretoria.

FOLEY,G. & BARNARD,G. (1984) "Farm and Community Forestry", Earthscan Energy Information Programme, IIED, London.

FTEE (1986) "World Status: Fuelwood", Financial Times Energy Economics, Issue 52, February, pp 7-11.

GANDAR, M.V. (1988) "The History and Experience of Woodlot Development for Fuelwood Production in Southern Africa", in Eberhard, A.A. & Williams, A.T. (eds) Renewable Energy Resources and Technology Development in Southern Africa, Elan Press, Cape Town

KRISTOFERSON, L.A. & BOKALDERS, V. (1986) "Renewable Energy Technologies: Their Application in Developing Countries", Beijer Inst., Pergammon Press, Oxford, U.K.

LAW,S.M. & EBERHARD,A.A, (1990) "A Directory of Rural Energy Programmes in Southern Africa", Draft Report, Centre for Research into Appropriate Energy TEchnology, University of Cape Town.

POWELL,P.I. & WELLINGS,P.A. (1983) "The Lesotho Woodlots Project: Progress, Problems and Prospects", in Development Studies Southern Africa, Vol.5, No.3, pp350-370

SAPPI (1985) "Project Grow", Information for Visitors, 14 March, SAPPI Forestry Ltd.

UNDERWOOD,M.J. (1985) "Transkei Community Woodlot Research Programme - An Agroforestry Approach", Report No.3/85, ARDRI, University of Fort Hare, Alice.

UNDERWOOD,M.J. (1988) "Agroforestry - Some Experiences from the ARDRI Research Programme", in Eberhard,A.A. & Williams,A.T. Renewable Energy Resources and Technology Development in Southern Africa, Elan Press, Cape Town.

VON DEM BUSSCHE,G.H. (1985) "Tree Planting in Gazankulu", Unpublished Report.

WHITE, R. (1979) "A Handbook for Village Woodlot Planning and Management in Botswana", NIR, University of Botswana, Gaberone.

4.3. Charcoal

BALDWIN, S.F. (1987) "Biomass Stoves: Engineering Design, Development and Dissemination", Volunteers in Technical Assistance, Arlington, VA, USA.

BENNIE, G. (1982) "A Survey of the Charcoal Manufacturing Industry in the Transvaal and Natal", Special Report: HOUT 225, National Timber Research Institute, CSIR, Pretoria.

EMRICH, W. (1985) "Handbook of Charcoal Making", Solar Energy R&D in the European Community, Series E, Vol.7, Energy From Biomass, Dordrecht.

FOLEY, G. (1988) "Discussion Paper on Demand Management", Eastern and Southern Africa Regional Seminar on Household Energy Planning, World Bank, Harare, 1-5 Feb, The Panos Institute, London.

HOSE, F.R. (1986) "Energy from Waste Wood and Invader Bush", Conf.Proc. Renewable Energy Potential in Southern Africa, 8-10 Sept, ERI, University of Cape Town.

HUY, V. (1984) "Can Charcoal Help to Overcome the Urgent need for Firewood?", Conf. Proc. Energy for Underdeveloped Areas, University of Cape Town.

KRISTOFERSON, L.A. & BOKALDERS, V. (1986) "Renewable Energy Technologies: Their Applications in Developing Countries", Beijer Institute, Pergannom Press, Oxford, U.K.

SHAW, G.D.H. (1989) "The Use of Alien Woody Biomass for Low-Cost, Small-Scale Charcoal Production, Energy Research Institute, University of Cape Town.

SORFA, P. (1983) "Study on the Availability and Demand for Wood Residues", Report No. HOUT/287, NTRI, CSIR, Pretoria.

4.4. Fuel Efficient Stoves

ATS Newsletter (1989) Ministry of Interior, Chieftainship Affairs and Rural Development, Kingdom of Lesotho, Maseru

DICKSON, B.J. & BALDWIN, S.A. (1990) "The Development of Low-Cost Fuel-Efficient Wood Burning Stoves Appropriate for Underdeveloped Areas of South Africa", Report No.GEN136, Energy Research Institute, University of Cape Town.

EVANS,I. & BOUTETTE,M. (1981) "Lorena Stoves: A Manual for Designing, Building and Testing Low-Cost Wood-Conserving Cookstoves", Volunteers in Asia, Stanford, Calif.

FOLEY, G., MOSS, P. & TIMBERLAKE, L. (1984) "Stoves and Trees", Earthscan, London.

HARRISON, P. (1980) "Appropriate Technology: How can it Reach the Villages?" New Scientist, 20 November, pp 521-523.

LAW,S.M. & EBERHARD,A.A. (1990) "Directory of Rural Energy Programmes in Southern Africa", Unpublished Draft, Energy Research Institute, University of Cape Town.

PEAT WARWICK MITCHEL (1987) "Metal Stove Production and Marketing Study for ATS, Lesotho", UN Agency for International Development.

4.5 Biogas

CHEN RUCHEN (1981) "The Development of Biogas Utilisation in China", Biomass, Vol.1, pp39-46.

EBERHARD, A.A. (1984) "A Directory and Review of Appropriate Energy Technology Programmes in Southern Africa", Report No.89, Energy Research Institute, University of Cape Town.

FLAVIN, C. (1985) "China's Biogas Program Moving Forward Again", Solar Energy Intelligence Report, 23 December, pp.428-9.

FRY, L.J. "Practical Building of Methane Power Plants for Rural Energy Independence", L.J.Fry, Santa Barbara, USA.

KRISTOFERSON L.A. & BOKALDERS, V. (1986) "Renewable Energy Technologies: Their Application in Developing Countries", Beijer Inst., Pergammon, Oxford, U.K.

LAW, S.M. & EBERHARD, A.A. (1990) "A Directory of Rural Energy Programmes in Southern Africa", Unpublished Draft, Energy Research Institute, University of Cape Town.

SASSE, L. (1984) "Biogas Plants: Design and Details of Simple Biogas Plants", F.Viewag & Sons, Weisbaden.

RIVETT-CARNAC, J.L. (1982) "Biogas - A Literature Review", Inst of Natural Resources, University of Natal, Pietermaritzburg.

VAN BUREN, A. (Ed.) (1979) "A Chinese Biogas Manual", Intermediate Technology Publications, London.

WILLIAMS, A.T. & EBERHARD, A.A. (1986) "An Overview of Biogas Applications in Rural Southern Africa", Proceedings - Anerobic Conference, University of the Orange Free State, Bloemfontein.

4.6. Solar Cookers

EBERHARD, A.A. (1983) "Dissemination of Solar Ovens in Lesotho: Problems and Lessons", International Solar Energy Congress, Perth Australia.

EBERHARD, A.A. (1986) "Energy Consumption Patterns in Underdeveloped Areas in South Africa", Report No.94, November, Energy Research Institute, University of Cape Town

PINON, R. (1983) "About Solar Cookers", Lifestyle, Vol.2, No.2, pp 133-145.

THOMAS, J.P. (1984) "Solar Cooker Distribution and Assesment in KwaZulu Communities", in Bromberger, N. & Lea, J. (eds) Rural Studies in KwaZulu, University of Natal Press, Pietermaritzburg.

TULLY, N & LAWRENCE, A.G. (1979) "The Use of Solar Energy for Cooking", The South African Mechanical Engineer, Vol.30, No.4

4.7. Hotboxes

DEPT OF DEVELOPMENT AID (1986) "Opname oor die Gebruik van die Hooikis, Supercooker of Wonderbox", Pretoria.

GANDAR, M.V. & UDIT, P. (1988) "Evaluation of Hotboxes in Rural and Periurban Areas", Institute of Natural Resources, University of Natal, Pietermaritzburg.

IBRAHAM, M., WAHAB, M.A. & RAFIQUE, S. (1986) "The Fuelless Um Chula: The Haybox Principle in Bangladesh", Appropriate Technology, Vol.13, No.1, pp8-9.

4.8. Solar Water Heating

EBERHARD, A.A. (1986) "Energy Consumption Patterns in Underdeveloped Areas in South Africa", Report No.94, November, Energy Research Institute, University of Cape Town.

FRIEDMAN, I.B. (1984) "Basic Needs and Health in the Valley of a Thousand Hills", 2nd Carnegie Inquiry into Poverty and Development in South Africa, Conf Paper No.150, SALDRU, University of Cape Town.

KLEIN, G. & WYATT, A. (1978) "Solar Energy Experimentation and Training in the Mountains of Lesotho", Phase 3, Draft Report, AT International.

MCLEAN, D., BASSON, J.A. & JAMMINE, E.J. (1985) "Hot Water Use in Low-Income Households and the Ability of Integral Solar Water Heaters to Accommodate these Requirements", Report BOU/75, CSIR, Pretoria.

STONE, A. (1984) "A Case Study of Water Sources and Water Quality of the Chalumna/Hamburg Area of Ciskei", 2nd Carnegie Inquiry into Poverty and Development in South Africa, Conf Paper No.148, SALDRU, University of Cape Town.

4.9 Energy Efficient Housing

COOK, C.E. (1988) "Pie in the Transkei: The Search for (or Obstacles to) an Appropriate Built Environment in the Transkei", Architecture SA, Sept/Oct, pp64-5.

FUGGLE, R.F. (1971) Relationships Between Micro-Climatic Parameters and Basotho Dwelling Sites in the Marakabei Basin, Lesotho", South African Journal of Science, September, pp443-450.

NORRIS, P. (1982) "Passive Solar Heating in Lesotho Housing", Renewable Energy Technology Project, Ministry of Co-operatives and Rural Development, Kingdom of Lesotho, Maseru.

RETP (1982a) "Passive Solar Heating in Lesotho Housing", Renewable Energy Technology Project, Ministry of Co-operatives and Rural Development, Kingdom of Lesotho, Maseru.

RETP (1982b) "Towards a Warmer Rondawel", Renewable Energy Technology Project, Ministry of Co-operatives and Rural Development, Kingdom of Lesotho, Maseru.

SIEGFRIED, W.R. & HOUGH, J.H. (1986) "Adaptive Significance of Indigenous Hut Architecture in Transkei", South African Journal of Science, Vol.82, June, pp295-299.

WILSON, M. & THOMPSON, L. (Eds.) (1982) "A History of South Africa to 1870", 1982 Edition, Davip Philip, Cape Town.

4.10 Photovoltaics

BORCHERS, M.L. (1989) "A Decision Making Tool for Assessing Grid Electrification Versus Stand-Alone Power Supply Options for Remote Users" M.Sc.(Eng) Thesis, Energy Research Institute, University of Cape Town.

EBERHARD, A.A. (1986) "South African Energy Crisis: Some Suggested Strategies", 2nd Carnegie Inquiry into Poverty and Development in South Africa, Post Conf Series No.13, SALDRU, University of Cape Town.

MULLER, D. (1988) "The Use of Small Photovoltaic Systems for the Electrification of Off-Grid Homes", M.Sc. Thesis, Energy Research Institute, University of Cape Town.

SINCLAIR, D.J. (1989) "A Review of International and Local Developments in Photovoltaic Technology and Economics for Developing Countries", M.Sc (Eng) Thesis, Energy Research Institute, University of Cape Town.

4.11 Grid Electrification

BORCHERS, M. Energy Research Institute, University of Cape Town, Personal Communication.

CECELSKI, E. & GLATT,S. (1982) "The Role of Rural Electricity in Development", Discussion Paper, Center for Energy Policy Research, Washington, DC.

COWAN, W.D. (1986) "Rural Electrification in Developing Countries", Energy Research Institute, University of cape Town.

DINGLEY, C.E. (1988a) "Electrification: An International Perspective", Interim Report No.3, Dept of Electrical Engineering, University of Cape Town.

DINGLEY, C.E. (1988b) "Macro Cost Estimate for a National Electrification Programme", Interim Report No.15, Dept of Electrical Engineering, University of Cape Town.

DINGLEY, C.E. (1990) "Electricity for All in South Africa: The Need and the Means", Dept of Electrical Engineering, University of Cape Town.

ESKOM (1990) "Statistical Yearbook - 1989" Eskom, Johannesburg.

FLUITMAN, F. (1983) "The Socio-Economic Impact of Rural Electrification in Developing Countries: A Review of Evidence", World Employment Programme Working Paper No.126, International Labour Office, Geneva.

MUNASINGHE, M. (1988) "The Economics of Rural Electrification Projects", Energy Economics, January, pp3-17.

SAIRR (1987a) Social and Economic Update, No.1, South African Institute for Race Relations, 27 April.

SAIRR (1987b) Social and Economic Update, No.2, South African Institute for Race Relations, 27 July.

TOBICH, R.G. & DINGLEY, C.E. (1988) "A Cost Estimate for the Electrification of Rural Areas in the Ciskei", Interim Report No.10, Dept of Electrical Engineering, University of Cape Town.

TURNER, T.C. & DINGLEY, C.E. (1988) "The Electrification of The Transkei", Interim Report No.11, Dept of Electrical Engineering, University of Cape Town.

CHAPTER 5 - Strategies for Household Energy Supply in Underdeveloped Areas

BEINART, W. (1984) "Soil Erosion, Conservation and Ideas about Development: A South African Exploration 1900-1960", Journal of Southern African Studies, Vol.11, No.1, pp52-6.

BUNDY, C. (1988) "The Rise and Fall of the South African Peasantry", 2nd Ed., David Philip, Cape Town

DAVENPORT, T.R.H. (1987) "Can Sacred Cows Be Culled? A Historical Review of Land Policy in South Africa with some Questions about the Future", Development Southern Africa, Vol.4, No.3, pp388-400

KEEGAN, T. (1988) "Facing the Storm: Portraits of Black Lives in Rural South Africa", David Philip, Cape Town

McCLINTOCK, S.E. (1988) "An Integrated Rural Energy Strategy for the Upper Tugela Location , KwaZulu", Investigational Report No.35, Institute of Natural Resources, University of Natal, Pietermaritzburg.

SCHUMACHER, E.F. (1973) "Small is Beautiful: A Study of Economics as if People Mattered", Blond & Briggs, London.

STEWARD, F. (1985) "Basic Needs in Developing Countries", John Hopkins University Press, Baltimore.

STREETEN, P. ET.AL. (1981) "First things First: Meeting Basic Needs in the Developing Countries", Oxford Univ. Press, Oxford.